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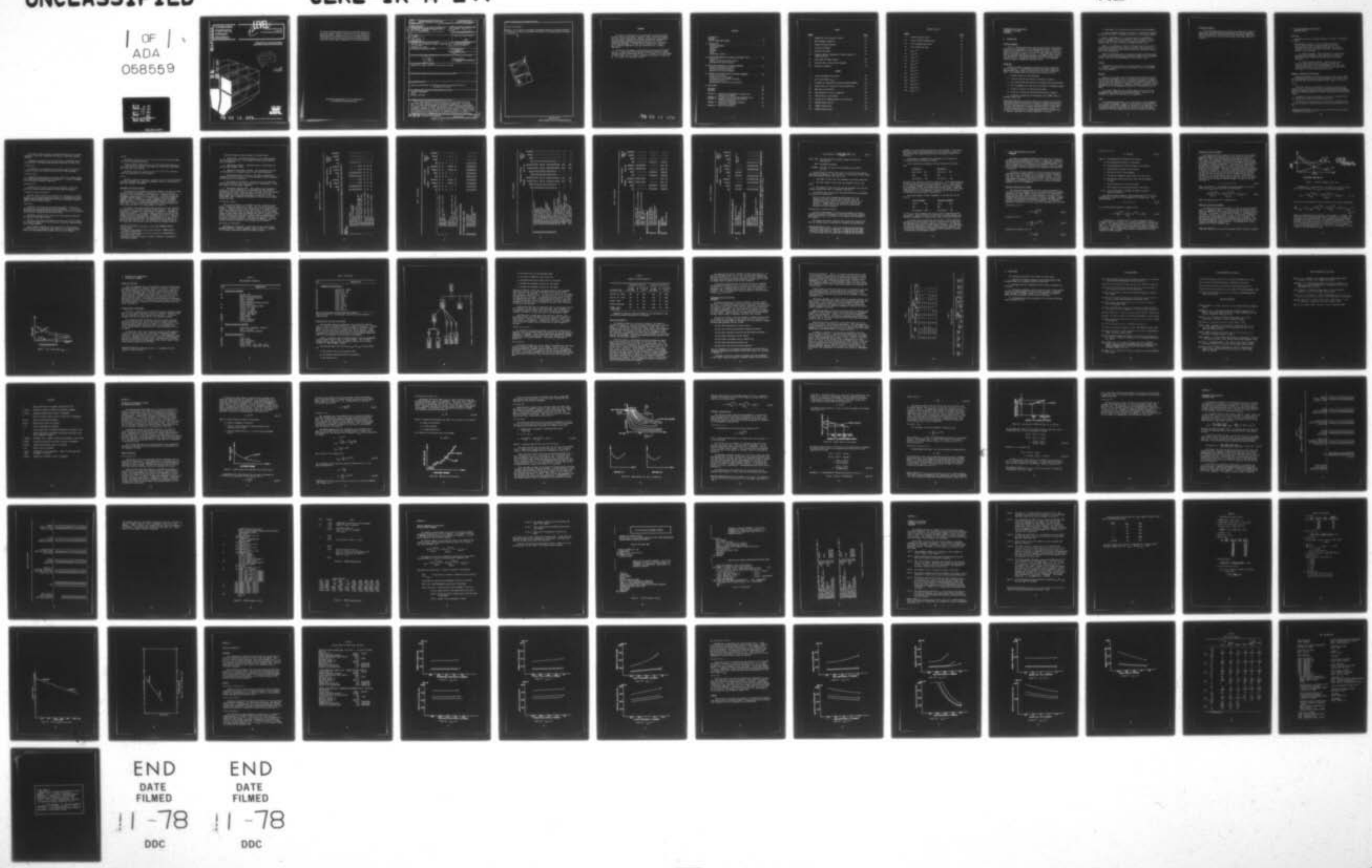

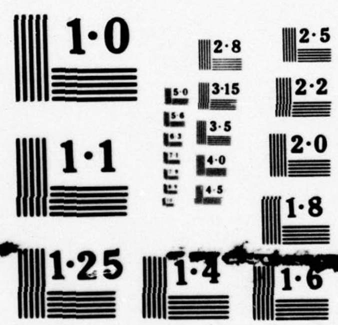

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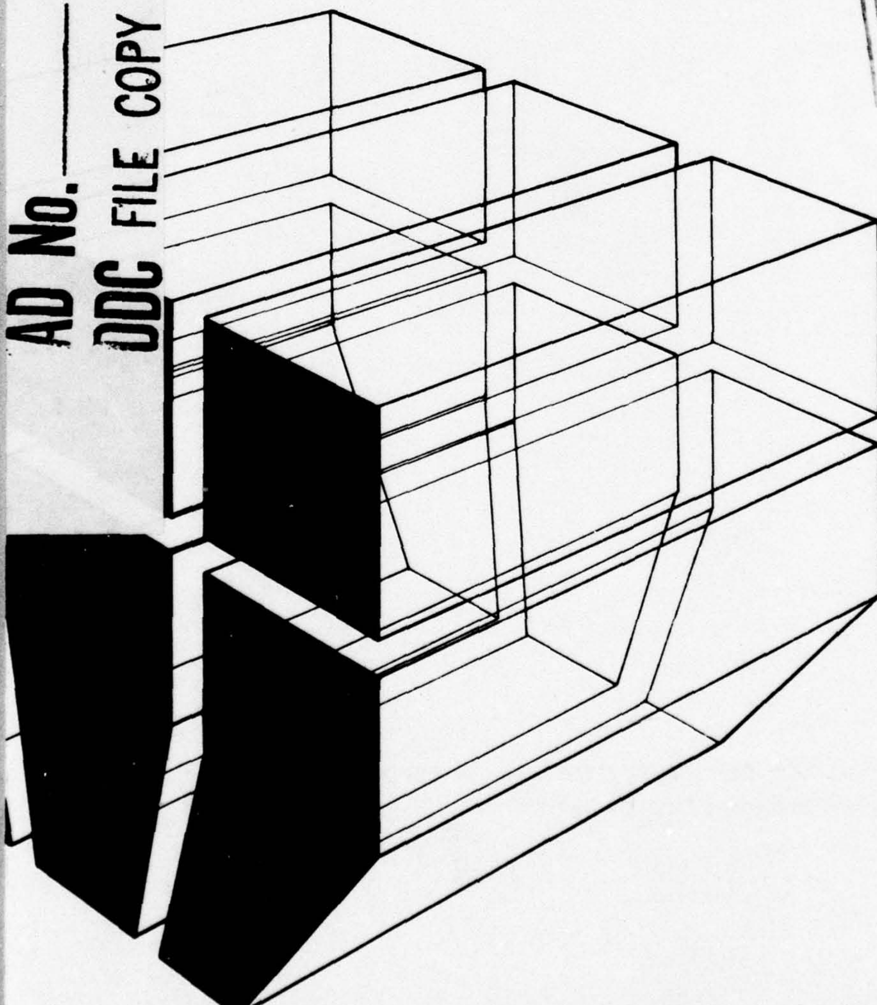
INTERIM REPORT M-247
July 1978
Facilities Engineering Equipment

METHODOLOGY FOR ESTABLISHING EQUIPMENT UTILIZATION STANDARDS



by
E. S. Lindow
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This report describes the first phase of a project designed to aid Army Facilities Engineers in improving equipment management. A rational basis for establishing equipment utilization standards was developed based on economic analyses of owning and operating costs. Mathematical models and automated procedures for their application are presented to compute minimum and objective utilization standards for equipment categories. Sample results are provided and the sensitivity of the model parameters is evaluated. Recommendations for implementing the utilization standards are also given. (over)

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Block 20 continued.

Results can be used in an equipment management program to establish uniform criteria for justifying equipment ownership and for gauging optimal equipment utilization.

FOREWORD

This work was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), RDT&E Army Program 6.27.31A; Project 4A762731AT41, "Design, Construction, and Operation and Maintenance Technology for Military Facilities"; Task 09, "Facilities Operation and Maintenance"; Work Unit 031, "Facilities Engineering Equipment." The OCE Technical Monitor was initially Mr. F. Koettner, DAEN-FEB-E, who was succeeded by Mr. J. Mason, DAEN-FEB-E.

The work was performed by the Engineering and Materials Division (EM), U. S. Army Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Mr. E. S. Lindow. Dr. G. Williamson is Chief of EM. COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Problem Statement

The U. S. Army maintains more than 200 installations with physical plants having a replacement value exceeding $65 billion.[1] Facilities engineers are responsible for the maintenance and repair functions on these installations, as well as for utility plant operation, fire protection, and other engineering services. To accomplish their mission, facility engineers must manage equipment inventories valued at more than $140 million. Economical and efficient use of this equipment inventory demands contemporary management tools.

Background

Existing equipment management procedures have been reviewed by several agencies,[2-4] including General Accounting Office (GAO), the Army Auditing Agency (AAA), and the Office of the Chief of Engineers (OCE). The problems identified through these reviews include:

1. Underutilization of some equipment
2. A lack of uniform and realistic utilization criteria
3. Less than optimum distribution of equipment among installations
4. Use of equipment for other than the originally intended purposes
5. A lack of criteria for authorizing purchase
6. A lack of criteria for prioritizing acquisition requests
7. Diversion of operating and maintenance, Army (OMA) funds to equipment acquisition

[1] *Facilities Engineering Management Handbook* (Directorate of Facilities Engineering, Office of the Chief of Engineers, January 1976 [Draft]).
[2] *Improved Inventory Management Could Provide Substantial Economics for the Army*, LCD-76-205 (U. S. General Accounting Office, 21 Nov 1975).
[3] *Developing Equipment Needs for Army Missions Requires Constant Attention*, LCD-75-442 (U. S. General Accounting Office, 10 May 1976).
[4] F. Koettner, Memorandum for Record, DAEN-FEB, 11 Feb 1976.

8. Requirement for extensive justification to procure equipment.

To improve equipment management procedures, a three-phase research project was initiated. The project consists of the following elements:

Phase I--Development of a uniform procedure for establishing realistic equipment utilization standards. These standards will prescribe the minimum usage required for equipment retention as well as optimal usage as a goal to minimize equipment ownership cost.

Phase II--Development of Tables of Allowance which can be used to identify the required minimum essential equipment fleet based on installation size, mission, and location and on the strength and capabilities of the organization.

Phase III--Development of an automated equipment inventory system which will provide data retrieval and analysis capability at Department of Army (DA), major command (MACOM), and installation levels.

Purpose

The purpose of this report is to address Phase I of the project; i.e., present a methodology establishing uniform, realistic equipment utilization standards.

Approach

Phase I of this study involved reviewing and evaluating existing Army equipment management policy; investigating the needs and capabilities of Facilities Engineers (FE) in equipment management; developing a rational basis for establishing equipment utilization standards; testing and evaluating the methods on a sample of equipment; and presenting the equipment utilization management procedures for implementation by the Army.

This report summarizes these accomplishments and discusses the mathematical and computerized techniques developed. Details of the mathematical methods are contained in the appendices.

Scope

The methodology developed in this study applies to the management of all types of equipment. However, since the goal of the project is to establish utilization standards for equipment in the Army Facilities Engineering inventory, the assumptions, data collection procedures, and application of the methods are specifically directed to that end.

Technology Transfer

It is anticipated that the results of this study will be used in establishing minimum and objective equipment utilization standards. Their development will have an impact on Army Regulation (AR) 310-34, *Equipment Authorization Policies and Criteria, and Common Tables of Allowance*.

2 EXISTING MAINTENANCE AND SERVICES EQUIPMENT POLICY

Definition

Maintenance and Services (M&S) equipment is defined in AR 420-83[5] as follows:

> M&S equipment includes all items of mobile equipment or special purpose vehicles and/or equipment with an end item acquisition cost of $1,000 or more which are used to accomplish facilities engineering functions. M&S equipment consists of the following:
>
> a. Mobile equipment. Mobile equipment is construction/maintenance type equipment, power-operated, power-drawn, or power propelled as differentiated from fixed or installed equipment.
>
> b. Special purpose vehicles. Vehicles which do not meet the definitions of mobile equipment but which are specially configured for the accomplishment of the facilities engineering mission and are not normally used for administrative support of other installation activities.

Summary of Applicable Publications

Numerous Department of the Army (DA) publications have an impact on the management and operation of M&S equipment. This section lists the principal publications and summarizes their impact on FE policy.

General

AR 310-34, *Equipment Authorization Policies and Criteria, and Common Tables of Allowances* (24 Feb 75), provides guidance on implementing DA equipment allowance and authorization policy and prescribes policy for including equipment in Tables of Distribution and Allowances (TDAs).

AR 420-22, *Preventive Maintenance and Self Help Programs* (6 Jul 76), establishes preventive maintenance practices.

AR 420-10, *FE--General Provisions, Organization, Functions, and Personnel* (30 May 75), defines terms, policies, and operations of the FE.

[5]*Maintenance and Services Equipment and Facilities Engineering Shops*, AR 420-83 (12 Jan 76), p 1-1.

AR 11-28, *Economic Analysis and Program Evaluation for Resources Management* (2 Dec 75), establishes DA policy for performing economic analyses.

AR 310-34, *Equipment Utilization Management*, establishes policy and procedures for managing M&S equipment (presently in draft form).

Authorization

AR 310-49, *The Army Authorization Documents System* (10 Jun 75), contains the basis for authorizing acquisition of M&S equipment.

Equipment Rental

AR 420-83, *M&S Equipment and FE Shops* (12 Jan 76), permits equipment rental when more economical than ownership. It gives a procedure for performing the economic comparison.

Equipment Pools

AR 420-17, *Real Property and Research Management* (13 Dec 76), authorizes loaning pooled equipment to other operating agencies.

Interservice Support Agreements

AR 1-35, *Basic Policies and Principles for Interservice, Interdepartmental, and Interagency Support* (29 Jun 73), authorizes the interchange of M&S equipment between DOD activities and meighboring federal agencies within a 25-mile radius.

Acquisition

AR 420-17, *Real Property and Research Management* (13 Dec 76), describes both acquisition and disposition procedures. It also lists controlled items of M&S equipment (see AR 420-30, *Supplies and Equipment*, for additional information on controlled items).

AR 725-50, *Requisitioning, Receipt and Issue System* (28 Jun 74), describes the procurement process.

AR 750-1, *Army Materiel Maintenance Concepts and Policies* (1 May 72), along with other ARs in the 750 series, prescribes required maintenance of M&S equipment.

Supply Bulletin (SB)700-20, *Army Adopted/Other Items Selected Authorization/List of Reportable Items* (Jan 77), is a supply bulletin listing all Army-adopted M&S equipment as well as unit prices.

Records

AR 420-83, *M&S Equipment and FE Shops* (12 Jun 76), describes usage rates for job accounting purposes.

Technical Manual (TM)38-750, *The Army Maintenance Management System (TAMMS)* (Nov 72), presents requirements for operational, maintenance, and historical record keeping.

AR 420-16, *Facilities Engineering Reports* (27 Jan 77), specifies reporting requirements for M&S Equipment.

Surveys

AR 570-7, *Equipment Management: Equipment Survey Program* (30 Jun 75), describes procedures for conducting equipment surveys at installations to ascertain equipment requirements.

Equipment Utilization Program

The purpose of an equipment utilization program is to obtain optimum use and efficient management of equipment so as to meet mission requirements with the minimum possible inventory. Equipment utilization management programs have been established in U. S. Army Development and Readiness Command (DARCOM), U. S. Army Training and Doctrine Command (TRADOC), and U. S. Army Forces Command (FORSCOM) through individual MACOM regulations.[6-8] An Army-wide management program is presently in draft form.[9] Although slight differences exist in the utilization criteria, the basis for all of these programs is identical.

In essence, each program establishes utilization criteria (minimum and objective) for selected categories of M&S equipment. The usage of each piece of equipment in an installation's inventory is recorded and summarized quarterly. This usage is then converted to utilization and compared with the minimum standard. Equipment which does not meet the minimum utilization standard should be declared excess (i.e., turned in to the Property Disposal Office for redistribution or salvage) or its retention should be justified. The objective utilization standard is not a decision criterion but a goal for effective equipment ownership.

[6] *Installation Equipment Management Program*, AMC (DARCOM) R700-64 (20 Dec 1974).

[7] *Utilization of Maintenance and Services Equipment*, TRADOC Regulation 420-4 (30 Nov 1973).

[8] *Utilization of Maintenance and Services Equipment*, FORSCOM Regulation 420-4 (6 Dec 1973).

[9] *Equipment Utilization Management*, Change in Chapter 5 and Appendix F of AR 310-34 (1976).

Terms which apply to these programs are defined below.

1. Utilization. The normal operation or use of M&S equipment for the purpose for which it was designed and obtained expressed in hours of operation.

2. Utilization criteria. Standards of use as established for specific M&S equipment items.

3. Objective utilization criterion. The percentage of utilization considered as a reasonable goal for each item of equipment.

4. Minimum utilization criterion. The lowest acceptable percentage of utilization for an item of M&S equipment without documented justification for its retention.

5. Percentage of utilization. The time an item is effectively used during a specific time frame expressed as a percentage of a given base figure, less maintenance downtime.

6. Maintenance downtime (MDT). MDT commences when equipment is turned in to the FE organization's maintenance shop for preventive maintenance and/or other repair services, including support maintenance, and ends when the item is reported ready for return to the user. Normal preventive maintenance performed by the operator is not considered MDT. MDT is computed and expressed in hours during the normal 40-hour work week.

Utilization Criteria

The selected categories of equipment and their respective utilization criteria are summarized in Table 1 for each of the existing programs. Although there are some discrepancies, this comparison illustrates the general uniformity of existing criteria in the four regulations. This uniformity has resulted from the adoption of the original standards established by AMC (now DARCOM) more than 10 years ago. These original standards were developed by panels based on experience with the various equipment categories. Revisions and additions to these standards have been made purely on "engineering judgment." Thus, the existing criteria are based on totally subjective assessments.

Percentage of Utilization

Percentage of utilization is calculated for each piece of M&S equipment quarterly. Actual equipment usage, in hours, is converted to utilization percentage through the following formula:

Table 1

Comparison of Utilization Criteria*

		PERCENTAGE CRITERIA								YEARS OF USEFUL LIFE			
		MINIMUM				OBJECTIVE							
		AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM
Commercial-design administrative-use vehicles managed by vehicle group code AR 58-18.													
VEHICLE GROUP CODE													
A	Automobile, sedan	50	50	—	—	65	65	—	—	6	—	—	—
B	Bus, BOC-Up to 37 passenger	45	45	—	—	80	80	—	—	8	—	—	—
C	Bus, BOC-Over 37 passenger	50	50	—	—	80	80	—	—	10	—	—	—
D	Bus, integral	50	50	—	—	80	80	—	—	12	—	—	—
E	Automobile, station wagon	50	50	—	—	70	70	—	—	6	—	—	—
G	Truck, pickup, 1/2 ton (under 7000 GVW)	40	40	—	—	65	65	—	—	6	—	—	—
H	Truck, 1/4-3/4 ton (under 7000 GVW)	40	40	50	50	65	65	75	75	6	—	—	—
I	Truck & truck tractor, 1 ton (7000-9999 (GVW)	35	35	35	35	50	50	50	50	7	—	—	—
J	Truck & truck tractor, 1 1/2-2 ton (10000-11999 GVW)	35	35	35	35	50	50	50	50	8	—	—	—
K	Truck & truck tractor, 2 1/2 ton (12000-13999 GVW)	35	35	35	35	50	50	50	50	8	—	—	—
L	Truck & truck tractor, 3-4 ton (14000-18999 GVW)	5	35	35	35	50	50	50	50	8	—	—	—

Table 1 (Continued)

		PERCENTAGE CRITERIA								YEARS OF USEFUL LIFE			
		MINIMUM				OBJECTIVE							
		AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM
M	Truck & truck tractor, 5-10 ton (19000-39999 GVW)	30	30	30	30	50	50	50	50	10	—	—	—
N	Truck and truck tractor, 11 ton & over (40000 GVW & up)	15	15	15	15	25	25	25	25	12	—	—	—
P	Scooters	15	15	—	—	25	25	—	—	3	—	—	—
	Trailer	—	—	10	10	—	—	15	15	—	—	—	—
	Semitrailer	—	—	15	15	—	—	35	35	—	—	—	—
	Truck, up to 1 ton (includes truck mtn telephone, 3/4 ton)	—	—	60	60	—	—	80	80	—	—	—	—
	Truck, 1 ton and over (includes truck mtn telephone, 1 1/2 ton)	—	—	60	60	—	—	80	80	—	—	—	—
Construction and engineering equipment													
ECC (Equipment Category Code)													
NB	Mixer, bituminous	10	10	15	15	25	25	30	30	12	—	—	—
NB	Mixer, concrete	10	10	15	15	25	25	30	30	12	—	—	—
NB	Paver, concrete	10	10	20	20	25	25	40	40	12	—	—	—
NB	Paving machine, bituminous	10	10	20	20	25	25	40	40	12	—	—	—
NB	Spreader, concrete	10	10	20	20	25	25	40	40	12	—	—	—
NB	Distributors, GED	10	10	30	15	25	25	45	30	12	—	—	—

Table 1 (Continued)

		Percentage Criteria: Minimum AR	Minimum AMCR	Minimum TRADOC	Minimum FORSCOM	Objective AR	Objective AMCR	Objective TRADOC	Objective FORSCOM	Years of Useful Life AR	AMCR	TRADOC	FORSCOM
NC	Scraper, earth, self-propelled	15	15	15	15	30	30	30	30	12	—	—	—
NC	Scraper, earth, towed	15	15	15	15	30	30	30	30	12	—	—	—
ND	Tractor, full-tracked	30	30	20	20	50	50	40	40	12	—	—	—
ND	Tractor, agricultural	30	30			50	50			12	—	—	—
NE	Grader, road, motorized	15	15	25	25	30	30	40	40	12	—	—	—
NF	Crane shovel, crawler	15	15	15	15	30	30	30	30	12	—	—	—
NF	Crane shovel, truck	15	15	30	15	30	30	45	30	12	—	—	—
NF	Crane shovel, self-propelled	15	15			30	30			12	—	—	—
NG	Loader scoop, self-powered	15	15	15	15	30	30	30	30	12	—	—	—
NG	Tractor bucket loader	15	15	20	20	30	30	40	40	12	—	—	—
NH	Roller, motorized	10	10	25	15	25	25	40	25	12	—	—	—
NV	Auger, earth	10	10	15	15	25	25	30	30	12	—	—	—
NV	Ditching machine, self-propelled	10	10	15	15	25	25	30	30	12	—	—	—
NV	Sweeper, self-propelled	10	10	25	25	25	25	50	50	12	—	—	—
	Crushing and screening equipment			30	30			60	60		—	—	—
	Pump, cent., power driven, 166 GPM and up (excludes standby equip.)	—	—	15	15	—	—	30	30	—	—	—	—
	Subgrader, form riding			20	20			40	40				
	Support Equip., self-powered, concrete finishing; e.g., screeds, tampers, trowels, vibrators, etc.	—	—	15	15	—	—	30	30	—	—	—	—
	Tractor, fulltrack, mdm	—	—	25	25	—	—	50	50	—	—	—	—
	Tractor, wheeled, DED	—	—	20	20	—	—	35	35	—	—	—	—

Table 1 (Continued)

		PERCENTAGE CRITERIA								YEARS OF USEFUL LIFE			
		MINIMUM				OBJECTIVE							
		AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM
	Tractor, wheeled, GED	—	—	20	20	—	—	35	35	—	—	—	—
	Washing and screening plant, self-powered	—	—	30	30	—	—	60	60	—	—	—	—
	Trailer, shop van	—	—	15	15	—	—	35	35	—	—	—	—
	Truck, dump, earth moving (5-ton and up)	—	—	15	15	—	—	30	30	—	—	—	—
	Truck, dump, refuse	—	—	15	15	—	—	25	25	—	—	—	—
	Truck, shop van	—	—	25	25	—	—	50	50	—	—	—	—
Materials handling equipment													
PA	Crane truck, warehouse	20	20	—	—	35	35	—	—	12	—	—	—
PB	Truck, forklift, electric	15	15	—	—	25	25	—	—	12	—	—	—
PC	Truck, forklift, GED	25	25	—	—	50	50	—	—	12	—	—	—
PE	Tractor, wheeled, warehouse	25	25	—	—	50	50	—	—	12	—	—	—
PF	Truck, straddle-carry	20	20	—	—	35	35	—	—	12	—	—	—
Support equipment													
QB	Generators	20	20	20	20	40	40	40	40	12	—	—	—
QC	Compressors	20	20	15	15	40	40	30	30	12	—	—	—
QD	Pumps	10	10	—	—	20	20	—	—	12	—	—	—
QG	Welding machines	20	20	20	20	40	40	40	40	12	—	—	—

Table 1 (Continued)

		PERCENTAGE CRITERIA								YEARS OF USEFUL LIFE			
		MINIMUM				OBJECTIVE							
		AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM	AR	AMCR	TRADOC	FORSCOM
Vehicles, special purpose/design, commercial													
VB	Truck, dump (construction)	40	40	—	—	60	60	—	—	(See vehicle group)			
VD	Truck, hopper	15	15	—	—	25	25	—	—				
VE	Truck, maintenance	60	60	—	—	80	80	—	—				
VF	Truck, refuse-collection	50	50	—	—	70	70	—	—				
Seasonal equipment (utilization applies to season)													
	Snowplows	15	—	15	15	35	—	35	35	12	—	—	—
	Snowblowers	15	—	15	15	35	—	35	35	12	—	—	—
	Mowers, lawn	40	—	40	40	65	—	65	65	12	—	—	—
	Tree planters	35	—	35	35	50	—	50	50	12	—	—	—
	Tree spades	25	—	25	25	50	—	50	50	12	—	—	—
	Pest control spray and fog machine	30	—	30	30	60	—	60	60	12	—	—	—
	Lawn/grounds sweepers	40	—	40	40	65	—	65	65	12	—	—	—

* From AMC Regulation 700-82, Appendix A; TRADOC Regulation 420-4, Appendix A; FORSCOM Regulation 420-4, Appendix A; and Army Regulation 310-34, Appendix F (Draft).

$$\% \text{ utilization} = \frac{\text{actual hours used}}{\text{500-MDT}} \times 100 \qquad \text{[Eq 1]}$$

where 500 = the total hours per quarter (based on 8 hours per working day)

MDT = maintenance downtime

500-MDT = the hours per quarter the equipment was available for use.

The definition of "actual hours used" is critical to the uniform application of Equation 1. Past reviews[10] of installation records showed that three separate definitions were in use:

1. The number of hours that the equipment was actually operating

2. The total number of hours that the equipment was on a job site

3. The number of hours from the time the equipment left the yard (normal storage area) until it returned to the yard.

To alleviate this situation the following definition was proposed for inclusion in AR 310-34:[11]

> The use of Facilities Engineering M&S Equipment will be reported for actual operating time, transport time, and limited delays (e.g., road roller waiting for asphalt to be spread, or a loader waiting for a dump truck while at the job site). Storage time at the job site for convenience purposes will not be reported.

Disadvantages in Existing Program

The major disadvantages in the existing equipment utilization program are related to the manner in which the utilization standards were established and to the method of calculating the percentage of utilization.

The present utilization standards were established subjectively. Thus, no rational basis is provided for reviewing and updating the

[10] Disposition Form, Subject: Facilities Engineering M&S Equipment Utilization Reporting, from DAEN-FEM-F to DAEN-FEB (19 Dec 1975).
[11] Disposition Form, Subject: Facilities Engineering M&S Equipment Utilization Reporting, from DAEN-FEM-F to DAEN-FEB (19 Dec 1975)

standards nor for developing standards for new equipment. Since equipment costs, models, and productivity rates are constantly changing, a rational basis for establishing realistic utilization criteria is a necessity.

The drawbacks in computing the percentage of utilization are illustrated by the following two examples.

First, consider two bulldozers with the following utilization data.

Bulldozer A		Bulldozer B	
Hours used	100	Hours used	200
MDT	300	MDT	0
Utilization	50%	Utilization	40%

Bulldozer A was used only one-half as much as B. It was down 60 percent of the time, while B was not out of commission at all. Yet bulldozer A has a higher percentage of utilization than B. Carrying this example to the extreme, a piece of equipment could be used 1 hour, be down the remaining 499 hours, and have a utilization of 100 percent. (Note that, using Equation 1, if the equipment is down for the full quarter, its utilization percentage becomes indeterminant.)

The second example involves lawnmowers in various parts of the country.

Texas Lawnmower		Minnesota Lawnmower	
Hours	500	Hours	200
MDT	0	MDT	0
Utilization	100%	Utilization	40%

In this case, both lawnmowers were used as much as necessary during the quarter. However, because of differences in growing seasons, the Minnesota lawnmower has a significantly lower utilization percentage.

To rectify these disadvantages and provide a uniform, Army-wide equipment utilization program, realistic procedures for establishing and implementing utilization standards are necessary. The remainder of this report describes a rational method of establishing utilization standards for M&S equipment based on the economics of ownership, and the procedures necessary for implementing these standards to provide a uniform and sound management program.

3 BASIS FOR DEVELOPING UTILIZATION STANDARDS

An effective equipment management program requires two types of standards governing equipment utilization. A lower limit, defined as the minimum utilization standard, is set as a management decision criterion to determine if the workload merits equipment ownership. The second standard, defined as objective utilization, is set as a management goal which stipulates optimum use for equipment after ownership is justified.

The purpose of these standards is first to assure that mission requirements are accomplished with the minimum essential equipment fleet and, second, to optimize use of equipment on hand. The underlying basis, then, for establishing utilization standards is to provide economy in equipment ownership within DA. Thus, an analytical framework for establishing the standards must incorporate equipment ownership costs in its foundation.

Owning and Operating Cost Model

The owning and operating O&O cost for a piece of equipment is a function of multiple parameters which include depreciation, investment, maintenance and repair (M&R), and operating costs. By formulating a general O&O cost model based on these parameters, the total cost of equipment ownership can be derived for any type of equipment. Appendix A presents the theoretical development of the O&O cost model and the physical interpretation of each of the parameters. The resultant mathematical expressions for each of the cost parameters are as follows.

Depreciation Cost (D)

$$D = \frac{I - FIe^{-a\mu L_d}}{\mu L_d} \qquad \text{[Eq 2]}$$

Investment Cost (V)

$$V = \frac{iFI}{a\mu^2 L_d}(1-e^{-a\mu L_d}) \qquad \text{[Eq 3]}$$

Maintenance and Repair Cost (M)

$$M = K\mu^k L_d^k \qquad \text{[Eq 4]}$$

Operating Cost (P)

$$P = \text{constant} \qquad \text{[Eq 5]}$$

where D = the depreciation cost/hour of utilization

V = the investment cost/hour of utilization

M = the maintenance and repair cost/hour of utilization

P = the operating cost/hour of utilization

I = the initial cost of the equipment

F = the ratio of immediate resale value to initial cost

L_d = the average retention period of that type of equipment in years

μ = the utilization rate in hours per year

i = the interest rate during the period of utilization

a,K,k = cost coefficients to relegate the model to specific types of equipment.

By combining these parameters, the equipment O&O cost (C) can be determined as a function of the equipment's utilization rate. The O&O cost model is

$$C = D + V + M + P \qquad \text{[Eq 6]}$$

or, by substituting Equations 2 through 5 in 6,

$$C = \frac{I - FIe^{-a\mu L_d}}{\mu L_d} + \frac{iFI}{a\mu^2 L_d}\left(1 - e^{-a\mu L_d}\right) + K\mu^k L_d^k \qquad \text{[Eq 7]}$$

From Equation 7, the O&O cost for a type of equipment can be determined for any utilization rate μ when the equipment is retained for L_d years. This computed O&O cost is the cumulative cost in dollars per hour, i.e., the total O&O cost divided by the total number of hours of utilization. The following section presents the procedure for employing the O&O cost model in establishing minimum and objective utilization standards for M&S equipment.

Minimum Utilization Standard

The minimum utilization standard is the lowest level of equipment usage which would merit ownership (exclusive of special items, the retention of which must be supported by documented justification). Then, from a cost standpoint, the minimum utilization standard is the utilization rate below which it would not be economically justifiable to purchase or retain the equipment. Since the work on which equipment utilization is predicated must still be performed, this definition implies that an alternative means of access to equipment may be more economical than ownership. The general alternative to owning equipment is renting or leasing* it. Thus, the minimum utilization standard will be that rate at which the cost of owning and operating the equipment will be less than or equal to the cost of renting the same type of equipment, i.e., cost of owning ≤ cost of renting. Since the user's cost for renting includes the equipment rental rate (R) and the operating cost (P), the minimum utilization standard, in terms of the O&O cost model is

$$D + V + M + P \leq R + P \qquad \text{[Eq 8]}$$

Then, from Equation 7, the minimum utilization standard is the utilization rate (μ_{min}) which satisfies the relationship

$$\frac{I(1-Fe^{-a\mu_{min}L_d})}{\mu_{min}L_d} + \frac{iFI(1-e^{-a\mu_{min}L_d})}{a\mu_{min}^2 L_d} + K\mu_{min}^k L_d^h \leq R \qquad \text{[Eq 9]}$$

where the operating cost (P) is cancelled out.

Objective Utilization Standard

The objective utilization standard is a goal for optimal equipment usage. In economical terms, it is defined as the utilization rate at which the cumulative cost of owning and operating the equipment would be minimized. This concept is illustrated in Figure 1. As the hours of utilization increase, the cumulative costs for investment and depreciation decrease (in accordance with Equations 2 and 3). However, the M&R costs concurrently increase (in accordance with Equation 4). Thus, the cumulative O&O cost will decrease to a minimum point and then increase as the M&R cost becomes dominant. This minimum point is the objective utilization standard, μ_{obj}.

*The term "renting" will be used to represent either renting or leasing.

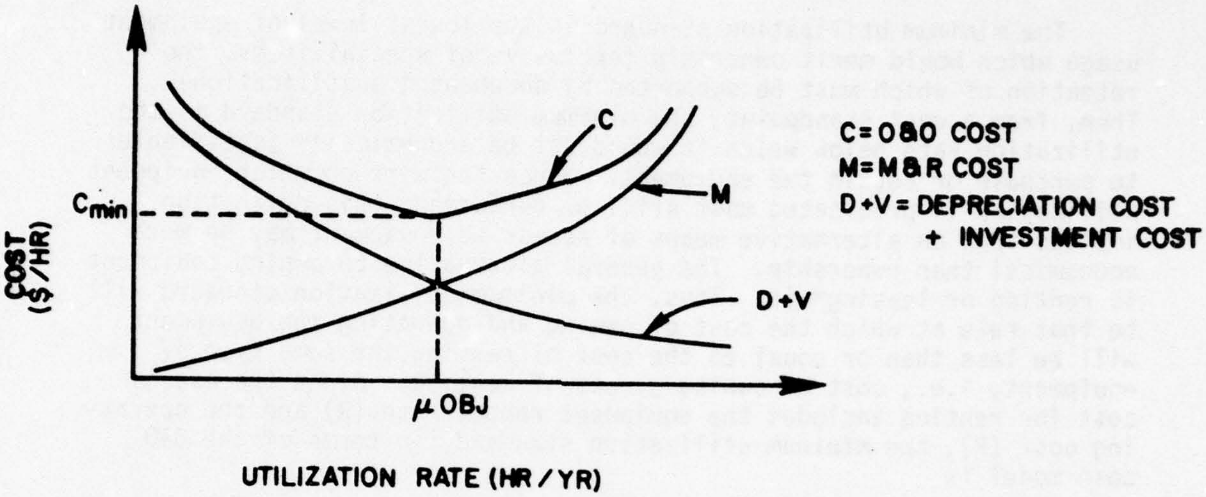

Figure 1. Typical equipment cost curves.

Mathematically, from Equation 7, the objective utilization standard is the utilization rate μ_{obj} which satisfies the equation

$$C_{min} = \frac{I(1-Fe^{-a\mu_{obj}L_d})}{\mu_{obj}L_d} + \frac{iFI(1-e^{-a\mu_{obj}L_d})}{a\mu_{obj}^2 L_d} + K\mu_{obj}^k L_d^k + P \qquad \text{[Eq 10]}$$

This rate can be determined from the solution of the partial differential

$$\left(\frac{\partial c}{\partial \mu}\right)_{\mu=\mu_{obj}} = \left(\frac{\partial}{\partial \mu}\right)_{\mu=\mu_{obj}} \left[\frac{I(1-Fe^{-a\mu L_d})}{\mu L_d} + \frac{iFI(1-e^{-a\mu L_d})}{a\mu^2 L_d} + K\mu^k L_d^h + P\right]_{\mu=\mu_{obj}} = 0 \qquad \text{[Eq 11]}$$

where, in differentiating the equation, the constant P is dropped. The possibility that the minimum O&O cost will correspond to an unrealistic utilization rate should be noted. This situation can occur when the equipment has a high initial cost and relatively low M&R cost. In this situation, illustrated by Figure 2, a maximum realistic utilization rate (μ') is assumed as the objective utilization rate. For this study, μ' is taken to be 2000 hours/year (i.e., the rate if the equipment is used 8 hours per day throughout the year).

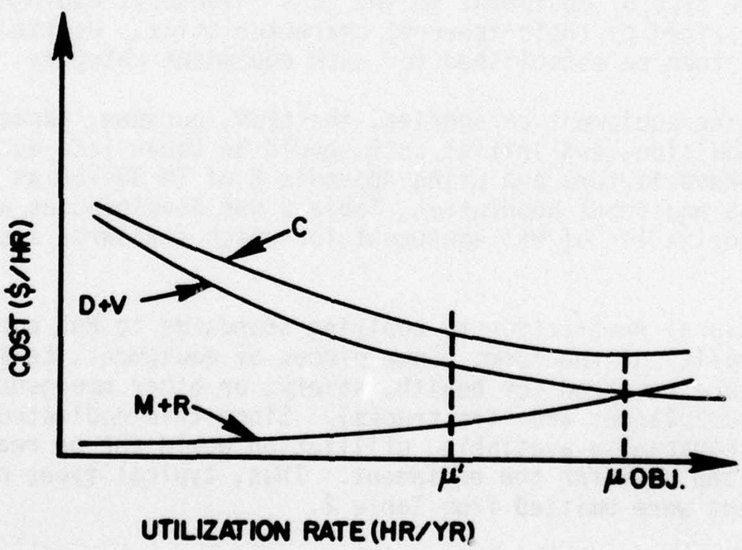

Figure 2. Cost curves where $\mu_{obj} > \mu'$.

4 PROCEDURE FOR ESTABLISHING UTILIZATION STANDARDS

Effect of Inflation

Since the component costs in the O&O model accrue at various rates throughout the period of equipment retention, the effect of inflation must be considered in applying the model. To provide a uniform basis for analysis, equipment costs can be normalized to remove inflation effects by discounting them to a present worth or to a worth in any common base year. Although either method may be used in calculating the utilization standards, discounting to a common base year was selected in this study. This method was chosen because many equipment data sources present costs in a manner which lends itself to discounting by economic indices.* Procedures for discounting equipment costs are given in Appendix B.

Categorization of Equipment

Since it is impractical to establish utilization standards for each model of every type of equipment in the FE's inventory, equipment items must be categorized by their inherent characteristics. Utilization standards can then be established for each equipment category.

In defining equipment categories, the type, purpose, capacity, method of propulsion, and initial cost should be taken into account. Considering these factors and using Appendix E of TM 38-750 as a listing of the M&S equipment population, Table 2 was developed as an initial categorization of M&S equipment for which standards could be developed.

An additional restriction to applying standards to M&S equipment is the criticality of the item. Some pieces of equipment, termed "dedicated," are required for health, safety, or other emergency situations (e.g., ambulances and fire trucks). Since this dedicated equipment must be constantly available, utilization would not be realistic indicator of the need for the equipment. Thus, typical types of dedicated equipment were omitted from Table 2.

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*Economic indices are published by the U. S. Department of Labor, Bureau of Labor Statistics.

Table 2

M&S Equipment Categories

ECC*		NOMENCLATURE
N	CONSTRUCTION EQUIPMENT	
NA		Crusher, rock
		Washing and screening plant
NB		Mixers, Bituminous material
		Mixers, concrete
		Pavers, concrete
		Paving machine, Bituminous material
NC		Ditching machine
		Scraper, Earth-moving, towed
ND		Tractor, FT, light
		Tractor, FT, heavy
		Tractor, FT, medium
		Tractor, wheeled, DED
NE		Grader, road, MTZD
NF		Crane-shovel
NG		Loader, scoop
NH		Rollers, motorized
NJ		Drilling machine
P	MATERIALS-HANDLING EQUIPMENT	
PA		Crane truck, warehouse, 10,000 lb
PB		Truck, lift fork
PE		Tractor, wheeled, warehouse
V	SPECIAL-DESIGN VEHICLES	
VC		Truck, F. F.
VD		Truck, hopper
VE		Truck, maintenance
VF		Truck, refuse
VJ		Truck Tractor, 1 HC, 5 Ton, 4 X 2
VT		Trailer, F. F., Pump Water, 500 GPM

Table 2 (Continued)

ECC*	NOMENCLATURE
I†	COMMERCIAL-DESIGN VEHICLES
IG	Semitrailer, lowbed
IG	Semitrailer, tank
IG	Semitrailer, van
II	Truck, cargo
IJ	Truck, carryall
IK	Truck, dump
IM	Truck, panel
IO	Truck, stake
IP	Truck, tank
IQ	Truck, tractor
IR	Truck, utility
IS	Truck, van
IT	Truck, wrecker

*ECC is the equipment category code from TM 38-750.
†Equivalent ECC i.e., the alphabetic part of ACVC (Army Commercial Vehicle Code).

Calculation of Utilization Standards

Each equipment category encompasses items from various manufacturers, as well as different models from a single manufacturer. Although similar in their initial price, usage, and capacity, the O&O cost parameters for all items within a category will not be identical. Therefore, to establish uniform standards for the entire equipment category, a procedure for calculating the standards is required which reduces the impact of cost parameter variations within the category.

Figure 3 illustrates the calculation procedure used to accommodate various equipment models within a single category. This procedure averages the μ_{min} and μ_{obj} for each model to obtain the utilization standards for the equipment category.

The required inputs for calculating μ_{min} and μ_{obj} for each model are:

I, the initial price of the equipment model

L_d, the average retention period of the equipment

i, the interest rate

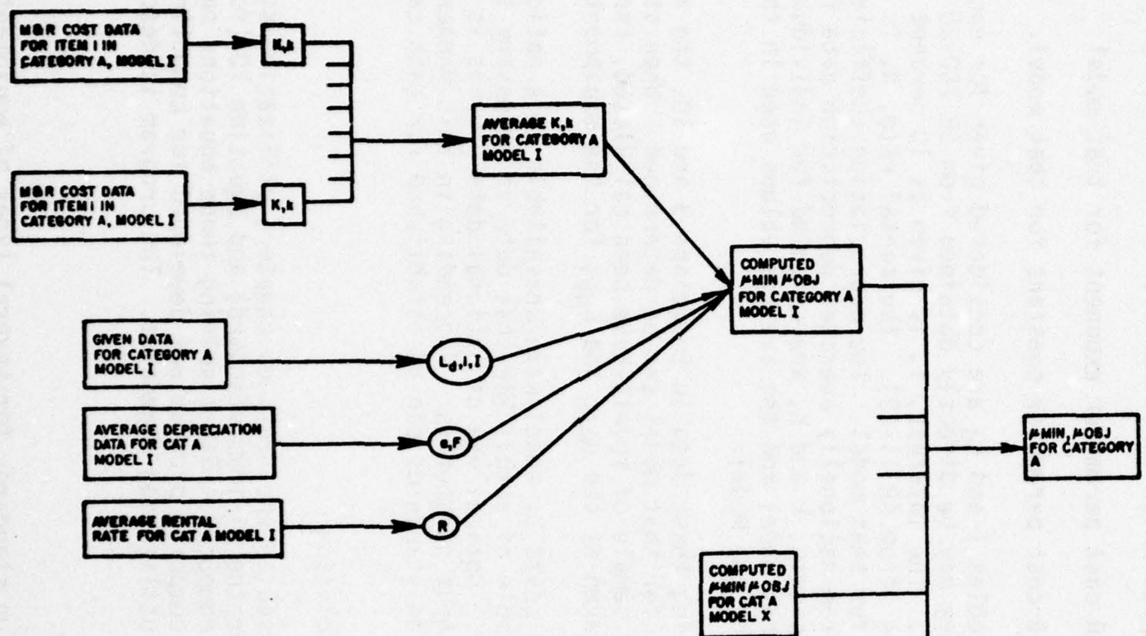

Figure 3. Procedure for applying utilization standards models.

R, the rental cost for the equipment model

F, the ratio of immediate resale value to I

a, the depreciation curve coefficient for that model

k, the M&R cost parameter exponent for that model

K, the M&R cost parameter constant for that model.

The input variables I and L_d are considered given for each equipment model since they may be directly obtained from SB 700-20 (I) and AR 310-34 (L_d). The interest, i, is given as 10 percent for all equipment categories (from AR 11-28). The rental rate, R, is the nationally averaged rate for that model. The depreciation coefficients, a and F, are computed from nationally averaged depreciation data for that model. The M&R coefficients, k and K, are computed for individual pieces of equipment of that model and the average values used in the calculation of standards for the model.

Substituting these data in Equations 9 and 10, the average utilization standards for that model can be determined. When standards for an appropriate sample of models have been calculated, the arithmetic averages are taken as the μ_{min} and μ_{obj} for the equipment category.

Since M&R costs by model were unavailable on a national scale, an adequate sample of actual M&R cost data is necessary to define this cost parameter. Optimal use of national data sources is made in defining other input parameters. Proceeding in this manner, representative utilization standards can be established for each category of equipment.

Computerized Solution

As discussed in the previous chapter, utilization standards from Equation 9 (for the minimum standard) and Equation 10 (for the objective standard) are computed. Since solving these equations manually becomes cumbersome, a computer program was developed for computing the minimum and objective utilization standards. The program is described in Appendix C.

Sample Results

Utilization standards for several types of equipment were calculated using the procedures developed in this chapter. Table 3 lists the minimum and objective standards based on the O&O cost of the equipment. Also shown in this table for comparison are the existing standards from AR 310-34. The existing standards are given as a percentage; multiplying this percentage by 2000 hours gives the utilization rate in hours per year.

Table 3

Sample Utilization Results

Equipment Type	Minimum Utilization by O&O Cost Model	by %	AR 310-34 hr/yr	Objective Utilization by O&O Cost Model	by %	AR 310-34 hr/yr
Tractor, FT, heavy	344	30	600	1013	50	1000
Tractor, FT, light	286	30	600	1129	50	1000
Loader, wheel	361	15	300	1144	30	600
Roller, motorized	458	10	200	1126	25	500
Grader, road, motorized	437	15	300	1485	30	600

Appendix D contains a detailed example of the application of the calculation procedure developed in this chapter.

Sensitivity Analysis

In applying a model to a real-world situation, the impact of averaged, estimated, or possibly inaccurate input data must be investigated. In establishing utilization standards, various input cost parameters are required. As described in this report, these parameters can be derived from historical records, national averages, or other published data. To determine the effect that each parameter has on the resulting minimum and objective utilization standard, a sensitivity analysis was performed. The procedure employed and the results of the analysis are provided in Appendix E.

From this analysis, the minimum utilization standard was determined to be sensitive to fluctuations in the rental cost. It also demonstrated a sensitivity to I, and, to a lesser degree, to F. The latter sensitivity is accentuated for equipment with a relatively low purchase price. Within the range examined, sensitivity to a, L_d, K, and k is not significant. The variables R, F, and I, to which μ_{min} does exhibit a sensitivity, have the least probability of erroneous selection since data sources on these variables are readily available. Even when an average value is used (e.g., price of similar equipment from several manufacturers or rental rate in different geographic locations), the range of the individual values for R, F, and I should seldom exceed 10 percent. Thus, the model is capable of providing realistic minimum utilization standards.

The objective utilization standard is highly sensitive to k. It exhibits some sensitivity to I, L_d, and K in the range examined and negligible sensitivity to a and F. The sensitivity to k demonstrates the necessity of obtaining representative data for M&R costs in order to produce realistic objective utilization standards.

It should be recognized that, of the two utilization standards, the minimum utilization is more critical since it forms a decision criterion (i.e., purchasing versus renting), while the objective is a management tool. Although precision of all inputs to the model is essential, special consideration should be devoted to those variables to which μ_{min} is sensitive.

Implementation of Utilization Standards

Minimum and objective utilization standards, in terms of hours per year, can be established rationally by using models developed in this study. As with many economic analysis techniques, the availability of historical cost records is the limiting factor in the precision of the standards developed. Their precision can be enhanced by using accurately recorded historical costs from a large sample of equipment in each category. Where possible, this sample should include records for each type or model of equipment covered by that category.

Because of the Army's large M&S equipment inventory and the scope of its reporting requirements, Army records should be sufficient to establish the necessary M&R cost parameters for each equipment category. Pertinent M&S equipment records include:

DA Form 2400--Equipment Utilization Record

DD Form 314--Preventive Maintenance Schedule and Record

DD Form 2404--Equipment Inspection and Maintenance Worksheet

DA Form 2408-9--Equipment Control Record

DA Form 2408-1--Equipment Daily or Monthly Log

DA Form 2405--Equipment Maintenance Log

DA Form 4125--Time and Distribution Register.

The cost parameters for investment, depreciation, and rental can be adequately determined from nationally published sources, as described in Appendix A.

Equipment utilization standards developed using the procedures of this report should be applied in a manner similar to the existing

policy (see Chapter 2). That is, utilization records should be kept for each piece of M&S equipment, the actual usage should be compared with the minimum standard to define underutilized equipment, and the actual usage should be compared with the objective standard to aid management in its goal of optimum equipment usage. The new utilization standards, however, will be expressed in hours per year, and thus their application will require that actual usage also be tabulated on a yearly basis.

Actual usage on an hours-per-year basis will average out peak and slack equipment demands, thereby reducing the frequency with which essential equipment must be justified during slack periods. Also, this method will allow direct application of the standards to seasonal equipment as well.

The actual equipment utilization should be tabulated monthly, with the utilization rate being the usage for the immediately preceding 12-month period. This procedure will provide equipment managers with constant information on equipment utilization and thus provide more frequent opportunities for employing management techniques to improve overall equipment utilization.

Reporting equipment utilization and justification of underutilized equipment to higher echelons should be performed annually (semiannual reports are now required). However, since utilization information will be available monthly, conscientious management would dictate that equipment that is consistently underutilized be identified and declared excess as early as possible.

Applying utilization standards as prescribed above will not increase the FE manual record-keeping requirements. With implementation of the Integrated Facilities System (IFS) at installations, manual record keeping will actually be reduced since DA Form 2400 and Forms AMC 1568-R, TRADOC 590-R, and FORSCOM 590-R will become unnecessary.

Information contained in the present IFS equipment utilization report is shown in Table 4. With only slight modification this report can be adapted to the application of utilization standards as proposed herein. The recommended report format is given in Table 5. The utilization tabulation for year-to-date (YTD) is changed to utilization rate, i.e., actual use during the preceding 12-month period. Additional columns are provided for the minimum and objective standards for each piece of equipment and for identifying underutilized equipment. Although maintenance downtime would no longer be included in computing utilization, this information is retained in the report as a management tool.

Table 4

Existing IFS Report

77 Apr 04 — Equipment Utilization Report FPO Installation

EQUIP	EQUIPMENT NAME	DATE OF MFR	SHOP CODE	HOURS POTEN-TIAL	DOWN	AVAIL-ABLE	IDLE	ACTUAL MONTH	USED YTD	PERCENT USED MONTH	YTD	OVER AGED FLAG
0070	Grain Drill	6601	08	152.0	.0	152.0	96.0	56.0	64.0	37	4	
0071	Grain Drill	7201	08	152.0	.0	152.0	144.0	8.0	24.0	5	1	
0091	Sealing Machine	7201	07	152.0	.0	152.0	152.0	.0	.0	0	0	
0117	Gen Van,Tr Mt	7101	12	152.0	.0	152.0	152.0	.0	.0	0	0	
0133	Grad,Rd,Mtized	6601	07	152.0	7.0	145.0	31.0-	176.0	884.0	121	54	*
0141	Grd,Rd,Mtized	6801	07	152.0	.0	152.0	48.0	104.0	312.0	68	20	
0142	Grader,Road	7509	07	152.0	120.0	32.0	48.0-	80.0	296.0	250	35	
0143	Grader,Road	7509	07	152.0	152.0	.0	16.0-	16.0	205.0	0	26	

Table 5

Modified IFS Report

Equipment Utilization Report

EQUIP CODE	EQUIP NAME	DATE OF MFR	SHOP CODE	HOURS POTEN-TIAL	DOWN	AVAIL-ABLE	IDLE	UTIL MONTH	ACT UTIL RATE	MIN UTIL RATE	OBJ UTIL RATE	UNDER UTIL FLAG	OVER AGE FLAG

5 CONCLUSIONS

The following conclusions can be drawn from this study:

1. Realistic utilization standards can be established for M&S equipment based on an economic analysis of O&O costs.

2. Necessary data for determining the utilization standards are available.

3. Utilization standards, given in hours per year, can be applied uniformly to M&S equipment including seasonal equipment. Comparing these standards to equipment usage for the immediately preceding 12 months provides advantages over the existing procedure.

4. Implementation of these standards will not require additional record keeping by the FE.

CITED REFERENCES

Army Adopted/Other Items Selected for Authorization/List of Reportable Items, SB 700-20 (Department of Army, Jan 1977).

Army Materiel Maintenance Concepts and Policies, AR 750-1 (1 May 72).

Basic Policies and Principles for Interservices, Interdepartmental, and Interagency Support, AR 1-35 (29 Jun 73).

Caterpillar Performance Handbook, 7th edition (Caterpillar Tractor Co., 1976).

Compilation of National Averaged 1975 Rental Rates for Construction Equipment (Associated Equipment Distributors, 1976).

Economic Analysis and Program Evaluation for Resource Management, AR 11-28 (December 1975).

Equipment Authorization Policies and Criteria, and Common Table of Allowances, AR 310-34, Appendix F, in draft version (24 Feb 75).

Equipment Management: Equipment Survey Program, AR 570-7 (30 Jun 75).

Equipment Utilization Management, AR 310-34 (presently in draft form).

FE-General Provisions, Organization, Functions, and Personnel, AR 420-10 (30 May 75).

Facilities Engineering Reports, AR 420-16 (27 Jan 77).

Installation Equipment Management Program, AMC R700-64 (20 Dec 1974).

Maintenance and Services (M&S) Equipment and Facilities (Engineering Shops, AR 420-83, January 1976).

National Research & Appraisal Company, *Green Guide; the Handbook of New and Used Construction Equipment Values* (Equipment Guide Book Co., 1977).

Neely, Edgar, Jr., *Construction Equipment Cost Guide*, Technical Report P-52 Basic Introduction/ADA016788; Vol I/ADA017271, and Volume II/ADA016910 (U.S. Construction Engineering Research Laboratory [CERL], Nov 75).

Peurifoy, R. L., *Construction Planning, Equipment and Methods* (McGraw-Hill, 1970).

CITED REFERENCES (Continued)

Preventive Maintenance and Self Help Programs, AR 420-22 (6 Jul 76).

Real Property and Research Management, AR 420-17 (13 Dec 76).

Requisitioning, Receipt and Issue System, AR 725-50 (28 Jun 74).

The Army Maintenance Management System (TAMMS), TM 38-750 (November 1972).

Utilization of Maintenance and Services Equipment, FORSCOM Regulation 420-4 (6 Dec 1973).

UNCITED REFERENCES

Alchian, Armen A., *Economic Replacement Policy* (Rand Publishing Company, 1952).

Benjamin, N. B. H., "Sensitivity Analysis of Douglas Equipment Life Model," *Proceedings*, American Society of Civil Engineers, Vol. 98, Col No. 8796 (March 1972), pp 61-73.

Charrin, J. R., "A Lease-or-Purchase Decision Model for the XYZ Corporation," *Management Services* (Sept-Oct, 1969).

Day, David A., *Construction Equipment Guide* (Wiley, 1973).

Douglas, James, "Optimum Life of Equipment for Maximum Profit," *Proceedings*, American Society of Civil Engineers, Vol 96, Col No. 5745 (Jan 1968), pp 41-54.

Douglas, James, *Construction Equipment Policy; The Economic Life of Machinery* (Stanford University, 1966).

Grant, Eugene L., W. Grant Ireson, and Richard S. Leavenworth, *Principles of Engineering Economy*, Sixth Edition (Ronald Press Company, 1976).

Harrison, L., "Equipment Option: Buy, Lease or Rent; Special Report," *Construction Methods & Equipment*, Vol 55 (Sept 1973), pp 91-96.

Hotelling, Harold, "A General Mathematical Theory of Depreciation," *Journal of the American Statistical Association*, Vol 20 (Sept 1925), pp 340-353.

UNCITED REFERENCES (Continued)

Mayer, R. R., "Problems in the Application of Replacement Theory," *Management Science*, Vol 7 (1960), pp 303-310.

Schrader, C. R., "Optimum Replacement Life of Large Scrapers," *Proceedings*, American Society of Civil Engineers, Vol 97, Col No. 8000 (March 1971), pp 37-52.

Smith, Vernon L., "Economic Equipment Policies; An Evaluation," *Management Science*, Vol 4 (Oct 1957), pp 20-37.

Taylor, J. S., "A Statistical Theory of Depreciation," *Journal of the American Statistical Association*, Vol 18 (Dec 1923), pp 1010-1023.

Wiersma, Charles M., "Economic Utilization of Fork Trucks," *Journal of Industrial Engineering*, Vol 8, No. 4 (April 1976).

Wolf, E. D., "Rent or Buy?" *Management Services* (Nov-Dec 1964).

NOTATION

a	Shape coefficient of equipment depreciation curve
C ($/hr)	Cumulative cost/hr of owning and operating equipment
D ($/hr)	Cumulative depreciation cost/hr of equipment
F	Ratio of initial resale value to initial cost of equipment
H (hr)	Hours of utilization equipment
HR (hrs)	Depreciation period of equipment
I ($)	Initial investment of equipment
K	Scale coefficient of equipment maintenance and repair curve
k	Shape coefficient of equipment maintenance and repair curve (KS in computer program)
L (years)	Equipment life: number of years that equipment is to be kept
M ($/hr)	Cumulative maintenance and repair cost/hr of equipment
O ($/hr)	Cumulative operating cost/hr of equipment
S ($)	Resale value of equipment
μ (hrs/year)	Utilization rate of equipment: number of hours/year that equipment is utilized
V ($/hr)	Cumulative investment cost/hr of equipment

APPENDIX A:

THEORETICAL DEVELOPMENT OF OWNING AND OPERATING COST MODEL

The owning and operating (O&O) cost of a piece of equipment includes all expenditures, both fixed and variable, which can be attributed to the acquisition and use of that equipment throughout its retention period. These expenditures are defined by the equipment cost parameters: depreciation, investment, maintenance and repair, and operating costs. In expressing O&O cost as a function of these parameters, the cumulative cost per hour is used. The cumulative cost per hour is the total cost (in dollars) divided by the total hours of utilization (in hours) for a given period of time. Since the extent of individual equipment utilization differs, the cumulative cost per hour provides a uniform basis for comparison of O&O costs.

In developing a model for equipment O&O costs, the effect of inflation must also be considered since costs accrue over several years. Equipment costs can be normalized to remove inflation effects by discounting them to a present worth or to an equivalent worth in any given base year. Since many equipment cost data sources use economic indices as published by the Department of Labor, Bureau of Labor Statistics, this method of discounting costs to a base year will be employed in the O&O cost model.

The following sections of this appendix present the mathematical formulation of the O&O cost model and the physical interpretation of the component variables.

Model Formulation

Depreciation Cost

Depreciation is the cost associated with the equipment's loss in value due to usage and age. Total depreciation is the difference between the price paid for the equipment and the price obtained when the equipment is sold or traded. Depreciation cost per hour is then the total depreciation divided by the hours of equipment utilization.

Several methods have been proposed for estimating equipment depreciation (e.g., straight line, declining balance, sum-of-the-year digit). Each method employs an estimate of the equipment's life and a formula for assigning a portion of the total depreciation to each period in that life. In reality, however, the equipment's resale value, and thus the total depreciation, is dependent on factors in addition to age. The mechanical condition, manufacturer, geographic location, introduction of more efficient models, and economic market will also influence the resale value.

To account for these factors, equation A1 was developed to express the resale value (S) as a function of utilization hours (H). Figure A1 illustrates this relationship. Since the resale value will never equal the initial investment (I), the ratio (F) of immediate resale value at time of purchase to initial investment has been introduced. In addition, the coefficient (a) is provided to account for the rate at which the resale value declines. Thus, this relationship provides the flexibility of expressing resale value for any type of equipment at any point in the equipment's utilization life.

$$S = FIe^{-aH} \qquad \text{[Eq A1]}$$

where S = resale value at H hours of utilization,

H = hours of equipment utilization,

I = initial cost of equipment including purchase price, delivery, service, etc.

F = ratio of resale value at H = 0 to the initial equipment cost, I.

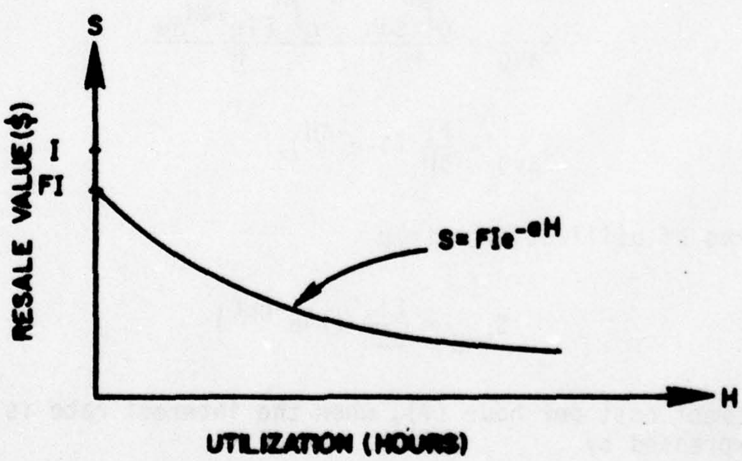

Figure A1. Resale value as a function of utilization hours.

From equation A1, total depreciation can then be expressed as $I - FIe^{-aH}$ and the depreciation cost per hour (D) is

$$D = \frac{I - FIe^{-aH}}{H} \qquad \text{[Eq A2]}$$

The hours of utilization (H) can be expressed in terms of the equipment's utilization rate (μ in hours per year) and the period the equipment is kept (L in years) by $H = \mu L$. Depreciation as a function of utilization rate is then

$$D = \frac{I - FIe^{-a\mu L}}{\mu L} \qquad \text{[Eq A3]}$$

Investment Cost

The investment cost for equipment typically includes interest on the money invested and all taxes, licensing, insurance, and storage fees. For the government-owned M&S equipment being considered, the stated fees are not incurred, but the interest on money invested must be considered in accurately assessing O&O cost. Thus, the investment cost would be the cumulative interest on the value of the equipment over the period of its retention.

The method commonly used* for estimating this investment cost is based on the average value of the equipment during its useful life. From equation A1, the average value of equipment (S_{avg}) can be determined as follows:

$$S = FIe^{-aH}$$

$$S_{avg} = \frac{\int_0^H S\,dH}{H} = \frac{\int_0^H FIe^{-aH}\,dH}{H}$$

$$S_{avg} = \frac{FI}{aH}(1 - e^{-aH}).$$

And in terms of utilization rate μ

$$S_{avg} = \frac{FI}{a\mu L}(1 - e^{-a\mu L}) \qquad \text{[Eq A4]}$$

The investment cost per hour (V), when the interest rate is i, can then be expressed by

$$V = i\,\frac{S_{avg}}{\mu}$$

$$V = \frac{iFI}{a\mu^2 L}(1 - e^{-a\mu L}) \qquad \text{[Eq A5]}$$

*Peurifoy, R. L., *Construction Planning, Equipment, and Methods* (McGraw Hill, 1956), p 50.

Maintenance and Repair Cost

Maintenance and repair (M&R) costs are those incurred to keep and restore operational capacity of equipment. These costs occur irregularly throughout the equipment's retention period. Figure A2 illustrates a typical plot of actual M&R cost per hour versus utilization hours (solid line). The peaks represent the instant at which the M&R is performed on the equipment. To approximate this relationship the best-fit smooth curve (dashed line) can be expressed by

$$M = KH^k \qquad \text{[Eq A6]}$$

where M = cumulative maintenance and repair cost per hour of utilization

H = hours of utilization

K = a scale constant

k = a sharp coefficient.

As a function of utilization rate, this becomes

$$M = K\mu^k L^k. \qquad \text{[Eq A7]}$$

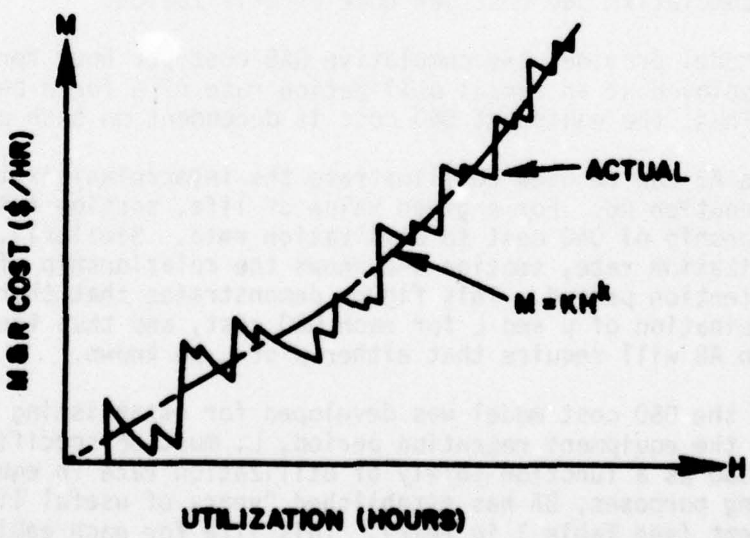

Figure A2. M&R cost vs utilization.

Since each type and model of equipment will have a unique M&R cost history, the coefficients K and k are used to define the curve characteristics for specific equipment.

Operating Cost

Operating cost includes final, operator's wage, and other costs necessary for the equipment operation. These costs will vary slightly due to mode of operation, geographic locale, and equipment age. However, in estimating the cumulative operating cost per hour, this deviation becomes insignificant. Thus, for this analysis, the operating cost per hour is expressed by the constant P.

O&O Cost Model

The owning and operating cost of a piece of equipment, as a function of its utilization rule and retention period, can now be expressed by integrating the previously discussed cost elements as follows:

C = depreciation + investment + maintenance and repair + operating

$$C = D + V + M + P$$

$$C = \frac{I(1-Fe^{-a\mu L})}{\mu L} + \frac{iFI(1-e^{-a\mu L})}{a\mu^2 L} + K\mu^k L^k + P \qquad \text{[Eq A8]}$$

where C = cumulative O&O cost per hour of utilization.

This model provides the cumulative O&O cost per hour for equipment which is employed at an annual utilization rate of μ for a period of L years. Thus, the equipment O&O cost is dependent on both μ and L.

Figure A3 can be used to illustrate the interrelationship of C, μ, and L in equation A8. For a given value of life, section A-A shows the relationship of O&O cost to utilization rate. Similarly, at a given utilization rate, section B-B shows the relationship of O&O cost life or retention period. This figure demonstrates that there is not a unique combination of μ and L for each O&O cost, and thus the solution of equation A8 will require that either μ or L be known.

Since the O&O cost model was developed for establishing utilization standards, the equipment retention period, L, must be specified in order to obtain O&O as a function solely of utilization rate in equation A8. For planning purposes, DA has established "years of useful life" for M&S equipment (see Table 1 in text). This life for each equipment type was determined from experience and manufacturers' recommendations as the average number of years the equipment can be expected to be used.

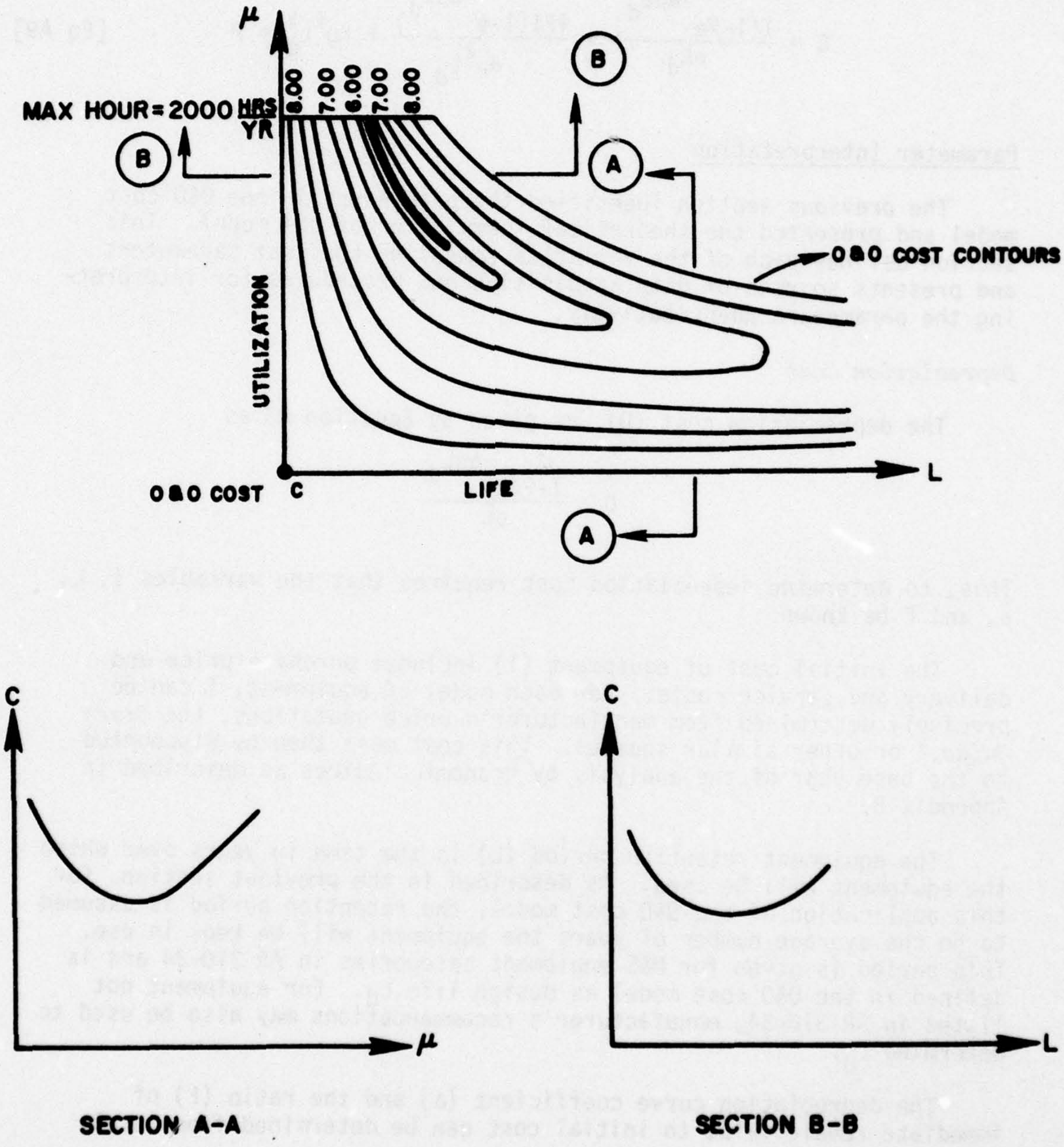

Figure A3. Relationship of μ and L to O&O cost.

Applying these values as the equipment design life (L_d) in Equation 9 produces the following equation in which O&O cost can be solved as a function of utilization rate.

$$C = \frac{I(1-Fe^{-a\mu L_d})}{\mu L_d} + \frac{iFI(1-e^{-a\mu L_d})}{a\mu^2 L_d} + K\mu^k L_d^k + P \qquad \text{[Eq A9]}$$

Parameter Interpretation

The previous section identified the parameters in the O&O cost model and presented the theoretical formulation of the model. This section defines each of the variables composing the cost parameters and presents sources of data acquisition and procedures for interpreting the parameters quantitatively.

Depreciation Cost

The depreciation cost (D) was given by Equation A3 as

$$D = \frac{I-FIe^{-a\mu L_d}}{\mu L}$$

Thus, to determine depreciation cost requires that the variables I, L, a, and F be known.

The initial cost of equipment (I) includes purchase price and delivery and service costs. For each model of equipment, I can be precisely determined from manufacturer's price quotations, the *Green Guide,** or other similar sources. This cost must then be discounted to the base year of the analysis by economic indices as described in Appendix B.

The equipment retention period (L) is the time in years over which the equipment will be used. As described in the previous section, for this application of the O&O cost model, the retention period is assumed to be the average number of years the equipment will be kept in use. This period is given for M&S equipment categories in AR 310-34 and is defined in the O&O cost model as design life L_d. For equipment not listed in AR 310-34, manufacturer's recommendations may also be used to determine L_d.

The depreciation curve coefficient (a) and the ratio (F) of immediate resale value to initial cost can be determined from resale

*National Research and Appraisal Company, *Green Guide: The Handbook of New and Used Construction Equipment Values* (Equipment Guide Book Co., 1977).

value data. The resale value (i.e., the dollar value obtained by sale, trade-in, or salvage of the equipment) must be obtained at various hours of utilization and discounted to the base year of the analysis. A semilog plot of these data, as shown in Figure A4, results in a linear trend and can be expressed by Equation A1:

$$S = FIe^{-aH}$$

The slope of this function is a log e, and the intercept on the resale value axis is FI.

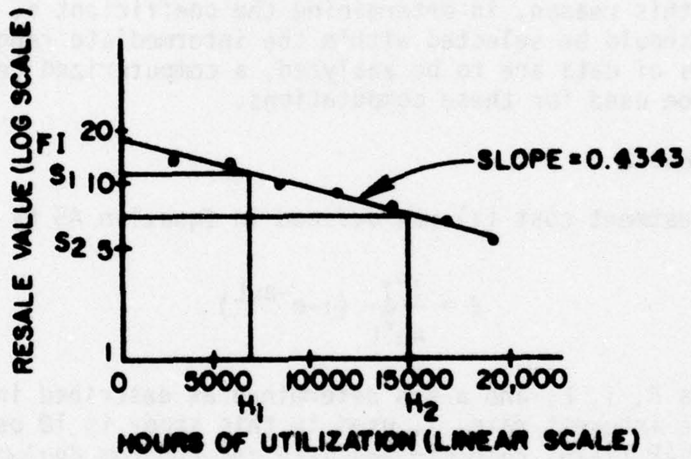

Figure A4. Resale value vs utilization.

By selecting two values of utilization (H_1 and H_2) and their corresponding resale values S_1 and S_2, the depreciation coefficient a can be determined as follows:

$$\log S_1 = \log FI - aH_1 \log e$$

$$\log S_2 = \log FI - aH_2 \log e$$

$$a = \frac{\log S_1 - \log S_2}{\log e\ (H_2 - H_1)}$$

or

$$a = \frac{\log S_1 - \log S_2}{-0.4343(H_1 - H_2)} \qquad \text{[Eq A10]}$$

Knowing a, F is determined by finding the value of S_3 at $H_3 = 0$.

$$\log S_3 = \log S_2 + 0.4343(a)(H_2) \qquad \text{[Eq A11]}$$

then, at $H_3 = 0$

$$F = \frac{S_3}{I} \qquad \text{[Eq A12]}$$

The required resale value-utilization data can be obtained from historical records, the *Green Guide, Construction Equipment Cost Guide,** or similar sources. In determining the best-fit straight-line relationship for the plotted data, some scatter in the data points can be expected at very low and very high utilization. However, within the range where normal trade-in would occur, typical data exhibit a linear trend. For this reason, in determining the coefficient a, values for utilization should be selected within the intermediate range. When large amounts of data are to be analyzed, a computerized regression routine may be used for these computations.

Investment Cost

The investment cost (V) was defined in Equation A5 by

$$V = \frac{iFI}{a\mu^2 L}(1-e^{-a\mu L})$$

The variables F, I, L, and a are determined as described in the previous section. The interest rate, i, used in this study is 10 percent as specified in AR 11-28, *Economic Analysis and Program Evaluation for Resource Management*.

Maintenance and Repair Cost

The maintenance and repair cost (M) was defined in Equation A6 by

$$M = KH^k$$

The coefficients K and k must be determined for each type of equipment. These coefficients can be empirically determined from historical M&R records. A log-log plot of M&R cost data (discounted to the base year of the analysis as per Appendix C) versus utilization hours produces a linear trend, as shown in Figure A5, where the slope is k and the intercept on the M&R cost axis is K.

---

*Neely, Edgar, Jr., *Construction Equipment Cost Guide*, Technical Report P-52 Basic Introduction/ADA016788; Vol I/ADA017271; and Vol II/ADA016910 (U.S. Army Construction Engineering Research Laboratory [CERL], Nov 75).

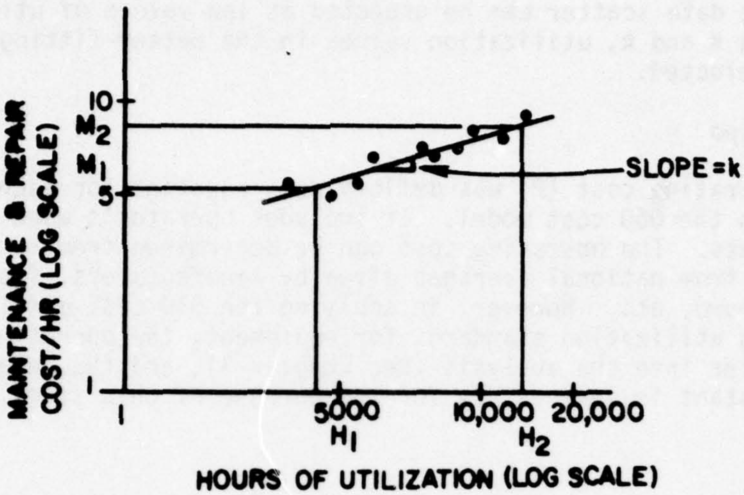

Figure A5. Log-log plot of M&R cost/hour vs utilization.

By selecting two values of utilization (H_1 and H_2) and their corresponding M&R costs, k can be calculated as follows:

$$\log M_1 = \log K + k \log H_1$$

$$\log M_2 = \log K = k \log H_2$$

$$k = \frac{\log M_2 - \log M_1}{\log H_2 - \log H_1} \qquad \text{[Eq A13]}$$

Knowing k, K is computed from

$$\log K = \log M_1 - \log H_1$$

$$K = \text{antilog}\,(\log M_1 - k \log H_1) \qquad \text{[Eq A14]}$$

The M&R cost-utilization data can be obtained by collating historical records from similar equipment. If these records are unavailable, national averages from the equipment industry* could also be

*For example, from the *Caterpillar Performance Handbook*, 7th edition (Caterpillar Tractor Co., 1976).

used. Since data scatter can be expected at low values of utilization, in computing K and k, utilization values in the better-fitting midrange should be selected.

Operating Cost

The operating cost (P) was defined as a constant for each type of equipment in the O&O cost model. It includes operator's wage, fuel, and lubricants. The operating cost can be determined from historical records, or from national averages given by manufacturers, from *Engineering News Record,* etc. However, in applying the O&O cost model to establishing utilization standards for equipment, the operating cost does not enter into the analysis (see Chapter 3), and thus quantification of this constant is unnecessary for the purpose of this study.

APPENDIX B:

PROCEDURE FOR DISCOUNTING
EQUIPMENT COSTS

As described in Appendix A, the equipment costs used in the O&O cost model must be discounted to account for the effect of inflation and provide for a uniform basis of comparison. The method used to discount costs employs economic indices as published by the Department of Labor, Bureau of Labor Statistics. Table B1 is a sample of prevailing economic indices for construction equipment.

To illustrate the use of the indices, consider a heavy tractor purchased in 1966 for an initial price of $41,900. If the base year for the analysis is 1975 (i.e., all costs in the O&O cost model will be equated to their dollar value in 1975), the initial price (I) of the heavy tractor in 1975 dollars would be

$$I_{1975} = \frac{\text{Econ Index (1975)}}{\text{Econ Index (1966)}} I_{1966} = \frac{188.3}{95.8} (\$41{,}900) = \$82{,}357.$$

Note that the yearly economic index is an average index for that year. If costs are tabulated monthly, the individual month's index should be used.

In applying the O&O cost model, the initial price (I), the resale values (S) at various utilization times, and the maintenance and repair costs (M) for various periods of utilization must be discounted to a base year. They can be discounted by applying the general formula:

$$\text{Discounted Cost} = \frac{\text{Econ Index (base year)}}{\text{Econ Index (act. cost year)}} \times \text{Actual Cost} \qquad \text{[Eq B1]}$$

This formula can be easily applied to discount initial price and resale value data. However, the maintenance and repair costs used in the O&O model are expressed in terms of the cumulative cost per hour. Since M&R cost data are usually tabulated as the total cost in each year of equipment operation, a preparatory step to reduce these data to a cumulative cost per hour (i.e., cumulative costs to that time divided by cumulative utilization to that time) is necessary prior to application of Equation B1.

To facilitate the mathematical manipulation of maintenance and repair cost data, a computer program has been developed to discount the data directly. This program, TRNSFM, is written in FORTRAN IV and operates on a CDC 6000 series computer. It can be easily modified for use on other computers. The program listing is given in Figure B1.

Table B1

Economic Indices
Department of Labor, Bureau of Labor Statistics

	Estimated Percentage Increase in the Economic Index				
Year	(All Inclusive) Construction Machinery & Equipment--Wholesale Price Index	Power Crane, Dragline, Shovels	Specialized Construction Equipment Ditcher Rollers	Scrapers & Graders Wholesale Price Index	Wheel & Crawler Tractors, Dozers, Loaders
1965	93.6	93.0	94.3	95.1	93.3
1966	96.5	96.7	97.9	97.5	95.8
1967	100.0	100.0	100.0	100.0	100.0
1968	105.7	104.9	105.2	105.3	106.8
1969	110.4	109.0	110.2	110.1	112.5
1970	115.9	114.7	117.7	115.2	117.0
1971	121.4	120.6	125.1	120.6	122.3
1972	125.7	126.0	129.0	124.4	127.0
1973	130.7	130.5	134.1	136.1	134.5
1974	152.3	152.2	151.3	160.4	154.7
1975	185.2	184.3	189.4	195.6	188.3
J 1976	193.3	196.2	197.0	204.0	196.9
F 1976	194.4	196.4	199.8	204.4	198.7
M 1976	194.7	197.2	200.4	205.4	198.7
A 1976	195.0	197.5	201.5	205.4	198.7
M 1976	196.4	197.8	202.2	207.4	200.5

Table B1 (Continued)

Estimated Percentage Increase in the Economic Index	Year	(All Inclusive) Construction Machinery & Equipment--Wholesale Price Index	Power Crane, Dragline, Shovels	Specialized Construction Equipment Ditcher Rollers	Scrapers & Graders Wholesale Price Index	Wheel & Crawler Tractors, Dozers, Loaders
	J 1976	197.9	199.3	203.8	212.3	201.6
	J 1976	199.8	201.8	205.3	213.4	203.8
	A 1976	200.0	202.5	206.4	213.4	203.9
	S 1976	200.9	203.3	207.7	213.9	204.8
1/2%	O 1976	201.9	204.3	208.7	215.0	205.8
1/2%	N 1976	202.9	205.3	209.7	216.1	206.8
1/2%	D 1976	203.9	206.3	210.7	217.2	207.8
1/2%	J 1977	204.9	207.3	211.8	218.3	208.8
1/2%	F 1977	205.9	208.3	212.9	219.4	209.8
1/2%	M 1977	206.9	209.3	214.0	220.5	210.8
1/2%	A 1977	207.9	210.3	215.1	221.6	211.9
1/2%	M 1977	208.9	211.4	216.2	222.7	213.0
1/2%	J 1977	209.9	212.5	217.3	223.8	214.1
1/2%	J 1977	211.0	213.6	218.4	224.9	215.2
1/2%	A 1977	212.1	214.7	219.5	226.0	216.3
1/2%	S 1977	213.2	215.8	220.6	227.1	217.4
1/2%	O 1977	214.3	216.9	221.7	228.2	218.5
1/2%	N 1977	215.4	218.0	222.8	229.3	219.6
1/2%	D 1977	216.5	219.1	223.9	230.4	220.7

The necessary input for the program is shown in Figure B2. The data are input as integers except for card 1 (alphanumeric) and card 5 (real numbers). Cards 1 through 5 are repeated for each piece of equipment in the analysis. A blank card must follow the final input card. Typical output of the program is shown in Figure B3.

```
      PROGRAM TRNSFM(INPUT,OUTPUT)
      REAL X(16),Y(16),IND(16),CUM(16),RES(16),CHR(16)
      INTEGER NAME(8),BLANK
      DATA BLANK/"          "/
   50 READ 100,(NAME(I),I=L,*)
  100 FORMAT(8A10)
      IF(NAME(1).EQ.BLANK)STOP
      READ 150,NUMBER
  150 FORMAT(I10)
      READ 200,(HR(I),I=1,16)
  200 FORMAT(16F5.0)
      READ 300,(X(I),I=1,16)
  300 FORMAT(16F5.0)
      READ 350,(IND(I),I=1,16)
  350 FORMAT(16F5.0)
      DO 600 I=1,NUMBER
      Y(I)=X(I)/IND(I)
      IF(I.EQ.1)CUM(I)=Y(I)
      IF(I.NE.1)CUM(I)=Y(I)+CUM(I-1)
      IF(I.EQ.1)CHR(I)=HR(I)
      IF(I.NE.1)CHR(I)=HR(I)+CHR(I-1)
      RES(I)=CUM(I)/CHR(I)
  600 CONTINUE
      PRINT 700,(NAME(I),I=1,8)
  700 FORMAT (///,10X,8A10)
      PRINT 1000,( HR(I),I=1,NUMBER)
      PRINT 1100,(  X(I),I=1,NUMBER)
      PRINT 1200,(IND(I),I=1,NUMBER)
      PRINT 1300,(  Y(I),I=1,NUMBER)
      PRINT 1400,(CUM(I),I=1,NUMBER)
      PRINT 1500,(CHR(I),I=1,NUMBER)
      PRINT 1600,(RES(I),I+1,NUMBER)
 1000 FORMAT(" HOUR ",16F8.0)
 1100 FORMAT(" COST ",16F8.0)
 1200 FORMAT(" INDEX ",16F8.3)
 1300 FORMAT(" DISCO ",16F8.0)
 1400 FORMAT(" CUMCO ",16F8.0)
 1500 FORMAT(" CU.HR ",16F8.0)
 1600 FORMAT(" CO/HR ",16F8.3)
      GO TO 50
      END
```

Figure B1. TRNSFM program listing.

Card	Columns	Input
1	1-80	Alphanumeric description of the equipment
2	9-10	Number of years in analysis
3	1-5	
	6-10	Utilization hours in
	11-15	year 1, 2, etc. to a maximum
	.	of 16 years
	.	
	.	
	75-80	
4	1-5	
	6-10	Cost incurred in year 1, 2, etc.
	.	
	.	
	.	
	75-80	
5	1-5	
	6-10	Relative economic index in
	.	year 1, 2, etc. (i.e., the index for the
	.	base year divided by the index for
	.	year 1, 2, etc.)
	.	
	75-80	

Figure B2. TRNSFM program input.

Caterpillar D8

Hour	1322.	1124.	1577.	1411.	1276.	261.	1069.	188.	292.
Cost	14318.	0.	14681.	0.	6428.	8960.	8647.	2980.	1433.
Index	.900	.933	.958	1.000	1.068	1.125	1.170	1.223	1.270
Disco	15909.	0.	15325.	0.	6019.	7964.	7391.	2437.	1128.
Cumco	15909.	15909.	31234.	31234.	37252.	45217.	52607.	55044.	56172.
Cu.Hr	1322.	2446.	4023.	5434.	6710.	6971.	8040.	8228.	8520.
Co/Hr	12.034	6.504	7.764	5.748	5.552	6.486	6.543	6.690	6.593

Figure B3. TRNSFM program output.

APPENDIX C:

COMPUTER PROGRAM FOR CALCULATION OF UTILIZATION STANDARDS

The computer program UTLSTD can be used to calculate equipment minimum and objective utilization standards. The program is written in FORTRAN IV and operates on a CDC 6000 series computer. It can be easily adapted to other computer hardware.

The program computes the minimum utilization from Equation 9 by finding the μ_{min}, which provides an O&O cost equal to or slightly less than the rental cost:

$$\frac{I(1-Fe^{-a\mu_{min}L_d})}{\mu_{min}L_d} + \frac{iFi(1-3^{-a\mu_{min}L_d})}{a\mu_{min}^2 L_d} + K\mu_{min}^k L_d^k \le R$$

The objective utilization computation determines the μ_{obj} which minimizes O&O cost from the following equation (Equation 10).

$$C_{min} = \frac{I(1-Fe^{-a\mu_{obj}L_d})}{\mu_{obj}L_d} + \frac{iFI(1-e^{-a\mu_{obj}L_d})}{a\mu_{obj}^2 L_d} + K\mu_{obj}^k L_d^k + P$$

Note that the minimum cost is found by the partial differential

$\left(\frac{\partial C}{\partial \mu}\right)_{\mu=\mu_{obj}}$ = 0 and thus the constant P (operating cost) drops out

Input data for each piece of equipment consists of two cards

Card 1 Col 1-80 Alphanumeric description of equipment

Card 2 Col 1-10 I Initial price of the equipment, in dollars

11-20 A Shape factor of the depreciation cost curve

21-30 F Ratio of initial salvage value to the new price of equipment

31-40 L Useful life of equipment in years

41-50 KS The exponent coefficient of maintenance and repair cost element

51-60 K Scale coefficient of maintenance and repair cost element

61-70 R Rental cost of equipment in dollars per hour.

Each input value on card 2 must have a decimal point. These cards are repeated for each type of equipment to be analyzed. Two blank cards must be inserted at the end of the data deck.

Figure C1 provides the UTLSTP program listing. Figure C2 is the program output for two models in the heavy tractor category.

```
C                 *************************************************
C                 *                                               *
C                 *        THE UTILIZATION STANDARDS PROGRAM      *
C                 *                                               *
C                 *************************************************
C
      PROGRAM UTLSTD(INPUT,OUTPUT)
      REAL K,KS,LD,F ,I,A,IS,R,DIFF,TEMP,NDIFF,ODIFF,TEMP1,TEMP2,ONDIFF
      INTEGER UMIN.UTRY,OOBJ,OUTRY,NAME(8)
C
C
C                   READ IN THE INPUT DATA
C
C
    5 READ 10,(NAME(J),J=1,8)
   10 FORMAT(8A10)
   50 READ 100,I,A,F,HR,LD,KS,K,R
  100 FORMAT (8F10.5)
      IF(K.EQ.O.)STOP
C
C                          OBJECTIVE UTILIZATION STANDARDS:  THE DO LOOP
C                          DETERMINES THE VALUE OF UITLIZATION RATE, IN
C                          INCREMENT OF 50 HOURS/YEAR , WHICH MEETS THE
C                          OBJECTIVE CRITERIA
C
C
      IS=0.10
      LIMHR=2000
      ODIFF=1000000.
      UNOBJ=0
      DO 1000 OUTRY=100,LIMHR
      TEMP=   (1.-EXP(-A*OUTRY*LD))/(OUTRY*LD)
      TEMP2=(1.-F*EXP(-A*OUTRY*LD))/(OUTRY*LD)
      ONDIFF=K*(OUTRY*LD)**KS+I*TEMP2+(IS*F*I*TEMP)/(A*OUTRY)
      IF(ONDIFF.GE.ODIFF) GO TO 1000
      ODIFF=ONDIFF
      UNOBJ=OUTRY
 1000 CONTINUE
```

Figure C1. UTLSTD program listing.

```
C
C
C                              MINIMUM UTILIZATION STANDARDS:  THE DO LOOP
C                              DETERMINES THE VALUE OF UTILIZATION RATE , IN
C                              INCREMENT OF 50 HOURS/YEAR, WHICH MEETS THE
C                              MINIMUM CRITERIA
C
C
  150 UMIN=0
      DIFF=1000000.
      DO 500 UTRY=100,UOBJ
      TEMP =  (1.-EXP(-A*UTRY*LD))/(UTRY*LD)
      TEMP2=(1.-F*EXP(-A*UTRY*LD))/UTRY*LD)
      NDIFF=K*(UTRY*LD)**KS+I*TEMP2+I*F*TEMP*IS/(A*UTRY)-R
      NDIFF=ABS(NDIFF)
      IF(NDIFF.GE.DIFF)GO TO 500
      DIFF=NDIFF
      UMIN=UTRY
  500 CONTINUE
C
C
C                             PRINT OUT THE COMPUTER MINIMUM AND OBJECTIVE RATES
C
C
      PRINT 1200,(NAME(J),J=1,8),I,A,F,LD,KS,K,R
 1200 FORMAT(///,20X,8A10,/,20X," INITIAL PRICE, I                        ",
     -F12.0,"  DOLLARS",/,20X," DEPRECIATION SHAPE FACTOR,A       ",F12
     -.7,/,20X," INITIAL SALVAGE VALUE: PRICE RATIO,F",F12.4,
     -/,20X," USEFUL LIFE, L                        ",F12.1,"  YEARS",
     -/,20X," M&R SHAPE FACTOR, KS                  ",F12.2,
     -/,20X," M&R SCALE FACTOR, K                   ",F12.7,
     -/,20X," RENTAL COST, R                        ",F12.2,"  DOLLARS/HR")
      PRINT 1300,UMIN,UOBJ
 1300 FORMAT(21X,"MINIMUM UTILIZATION RATE   ",I20,"  HOURS/YEAR",
     -/,21X,"OBJECTIVE UTILIZATION RATE ",I20,"  HOURS/YEAR")
      GO TO 5
      END
```

Figure C1 (Continued)

```
TRACTOR,FT,HEAVY:INTERNATIONAL TD-25 SER. B  185 HP DSL DIR DRV 48562 LB
 INITIAL PRICE, I                          60831.   DOLLARS
 DEPRECIATION SHAPE FACTOR,A             .0001074
 INITIAL SALVAGE VALUE: PRICE RATIO,F      .8302
 USEFUL LIFE, L                             12.0    YEARS
 M&R SHAPE FACTOR, KS                       1.02
 M&R SCALE FACTOR, K                     .0004554
 RENTAL COST, R                            21.09    DOLLARS/HR
 MINIMUM UTILIZATION RATE                    341    HOURS/YEAR
 OBJECTIVE UTILIZATION RATE                  998    HOURS/YEAR

TRACTOR,FT,HEAVY;INTERNATIONAL TD-25 SER B 230 HP   DSL PWR SHFT 48997 LB
 INITIAL PRICE, I                          67491.   DOLLARS
 DEPRECIATION SHAPE FACTOR,A             .0001025
 INITIAL SALVAGE VALUE:PRICE RATIO,F       .8297
 USEFUL LIFE, L                             12.0    YEARS
 M&R SHAPE FACTOR, KS                       1.02
 M&R SCALE FACTOR, K                     .0005052
 RENTAL COST, R                            22.87    DOLLARS/HR
 MINIMUM UTILIZATION RATE                    351    HOURS/YEAR
 OBJECTIVE UTILIZATION RATE                  995    HOURS/YEAR
```

Figure C2. Typical UTLSTD program output.

APPENDIX D:

EXAMPLE OF UTILIZATION STANDARDS CALCULATION PROCEDURE

This appendix provides an example of the calculation procedure discussed in Chapter 4 for establishing equipment utilization standards. These calculations are for the equipment category "Tractor, Full Track, Heavy." Within this category are several models for which standards can be derived. The standards for the category can then be established from the average of the standards for each model.

A data sheet is used to facilitate the procedure of computing standards for each model of equipment. Table D1 gives the completed data sheet for the model Caterpillar D-8, which is in the heavy tractor equipment category. Following is a description of each line on the data sheet.

Line 1: The equipment category is a grouping of similar models as given in Table 2 (see Chapter 4).

Line 2: Name and description of the specific model within the category can be found in SB 700-20 or TM 88-751.

Line 3: The initial price of the model and the date of the price are given in SB 700-20. The base year selected for this analysis is 1975. Economic indices for these years (see Appendix B) are used to discount the initial price.

Line 4: The interest rate is 10 percent as given in AR 11-28.

Line 5: The average retention period for equipment in the heavy tractor category is 12 years, as is given in AR 310-34 and TM 38-751.

Line 6: Depreciation data for this model are taken from the *Construction Equipment Cost Guide*.* In this case the resale values at each utilization time have been discounted to 1975, the base year of this analysis. For other data sources or base years, the actual resale value can be discounted as described in Appendix B. Figure D1 is a semilog plot of these depreciation data.

Line 7: The depreciation coefficient, a, is the slope of the depreciation data in Figure D1. By selecting two values of utilization and their corresponding resale values, a can be calculated from this formula.

*Neely, Edgar, Jr., *Construction Equipment Cost Guide*, Technical Report P-52 Basic Introduction/ADA016788; Vol I/ADA017271; and Vol II/ADA016910 (CERL, Nov 77).

Line 8: The ratio, F, of initial resale to initial price is the intercept on the resale axis of Figure D1. It is calculated from this formula using the discounted I from line 3.

Line 9: The maintenance and repair cost at various utilization times can be the averages for this model or the specific M&R history for equipment of this model. For this example, actual M&R histories of several Caterpillar D-8's were obtained from a large construction company. The data listed are for one piece of equipment. The M&R costs were discounted using the TRNSFM program (see Appendix B). Figure D2 is a log-log plot of these data.

Line 10: The M&R cost coefficient, k, is determined from this formula by selecting two utilization times and their corresponding M&R costs from Figure D2.

Line 11: Using k from line 10, this formula is used to compute the M&R cost constant K.

Line 12: The rental cost for a Caterpillar D-8 is obtained from *Compilation of Nationally Averaged 1975 Rental Rates for Construction Equipment*.* Since the monthly rate is used, the rental cost per hour is computed by dividing by 176 hours/month. This cost is then discounted to the base period of the analysis. Note that the rate is the average for 1975 and therefore must be discounted to January 1975.

Line 13: The UTLSTD computer program is used to calculate the utilization standards for this equipment model. The input values for I, L_d, a, F, and R are taken from lines 3, 5, 7, 8, and 12, respectively. These are the average values for all equipment of this model. However, since the M&R cost parameters K and k are for a specific piece of equipment, lines 9, 10, and 11 must be repeated for other equipment in order to determine the average K and k for this model. Because of the limited data available for this example, those calculations were performed for five pieces of equipment. The average values are: K = 0.0005566 and k = 1.02454.

Line 14: The UTLSTD program output provides the average μ_{min} and μ_{obj} for this model of equipment.

**Compilation of Nationally Averaged 1975 Rental Rates for Construction Equipment* (Associated Equipment Distributors, 1976).

Performing these calculations for several models of heavy tractor gives the following results:

Model	μ_{min}	μ_{obj}
1	341	998
2	331	995
3	397	1010
4	316	1048
Average	344	1013

From these results the utilization standards for the heavy tractor equipment category would be: μ_{min} = 344 and μ_{obj} = 1013.

Table D1

Data Sheet for Heavy Tractor

1. **Equipment Category:** Tractor, FT, Heavy
2. Equipment Model: Catepillar D-8; Ser. H; 235 HP; 47,900 lbs
3. Initial Price \$41,900 in 1966 (Econ. Index = 95.8)

   Discounted to base Jan. 1975 (Econ. Index = 170)

$$I = \frac{\text{Base EI}}{\text{Price EI}} \text{ Initial Price} = \frac{170}{95.8} (41{,}900) = \$74{,}353$$

4. Interest Rate, i = 10%
5. Design Life, L_d = 12 years
6. Depreciation Data:

YEAR	ECONOMIC INDEX	UTILIZATION HOURS (H)	ACTUAL RESALE	DISCOUNTED RESALE (S)
		1000		56,066
		2000		50,144
		3000		44,686
		4000		39,692
		5000		35,162
		6000		31,096
		7000		27,494
		8000		24,357
		9000		21,682
		10000		19,472
		11000		17,727
		12000		16,445
		13000		15,628

7. Depreciation Coefficient:

$$a = \frac{\text{Log } S_1 - \text{Log } S_2}{-0.4343(H_1 - H_2)} = \frac{\log(52000) - \log(19000)}{-0.4343(1800 - 10{,}200)} = 0.0001199$$

8. Initial Resale to Initial Price Ratio:

$$\text{Log } S_{H=0} = \text{Log } S_2 + 0.4343(a)(H_2) = \text{Log}(19000) + 0.4343(.0001199)$$
$$(10{,}200) = 4.8099$$

$$F = \frac{S_{H=0}}{I} = \frac{64{,}550}{74{,}353} = 0.868$$

Table D1 (Continued)

9. M&R Cost Data:

YEAR	ECONOMIC INDEX	UTILIZATION HOURS (H)	ACTUAL M&R COST	DISCOUNTED CUMULATIVE M&R COST/HOUR (M)
		2,638		3.28
		3,955		3.90
		5,610		4.72
		7,040		5.70
		8,642		5.11
		8,957		8.52
		10,239		7.73
		10,610		8.21

10. M&R Cost Coefficient:

$$k = \frac{\text{Log } M_2 - \text{Log } M_1}{\text{Log } H_2 - \text{Log } H_1} = \frac{\log(8.25) - \log(3.60)}{\log(9000) - \log(3300)} = 0.8265$$

11. M&R Cost Constant:

$$K = \text{antilog}(\text{Log } M_2 - k \text{ Log } H_2) = \log(8.25) - (0.8265)\log(3000)$$

$$= .0004449$$

12. Rental Cost:

$4653 per month __________ per week __________ per day

__________per hour

Year 1975 Economic Index 188.3

Discounted Rental Cost Per Hour, $R = \frac{170}{188.3} \cdot \frac{4653}{176} = \$23.87/\text{hr}$

13. UTLSTD Program Input:

Equipment Category/Model: Heavy Tractor/Cat D-8

$I = \$74,353$

$a = 0.0001199$

$F = 0.8608$

$L_d = 12$ years

$k = 0.8265$

$K = 0.868$

$R = 23.87$

14. UTLSTD Program Output

Minimum utilization standard = 341 hours/year

Objective utilization standard = 998 hours/year

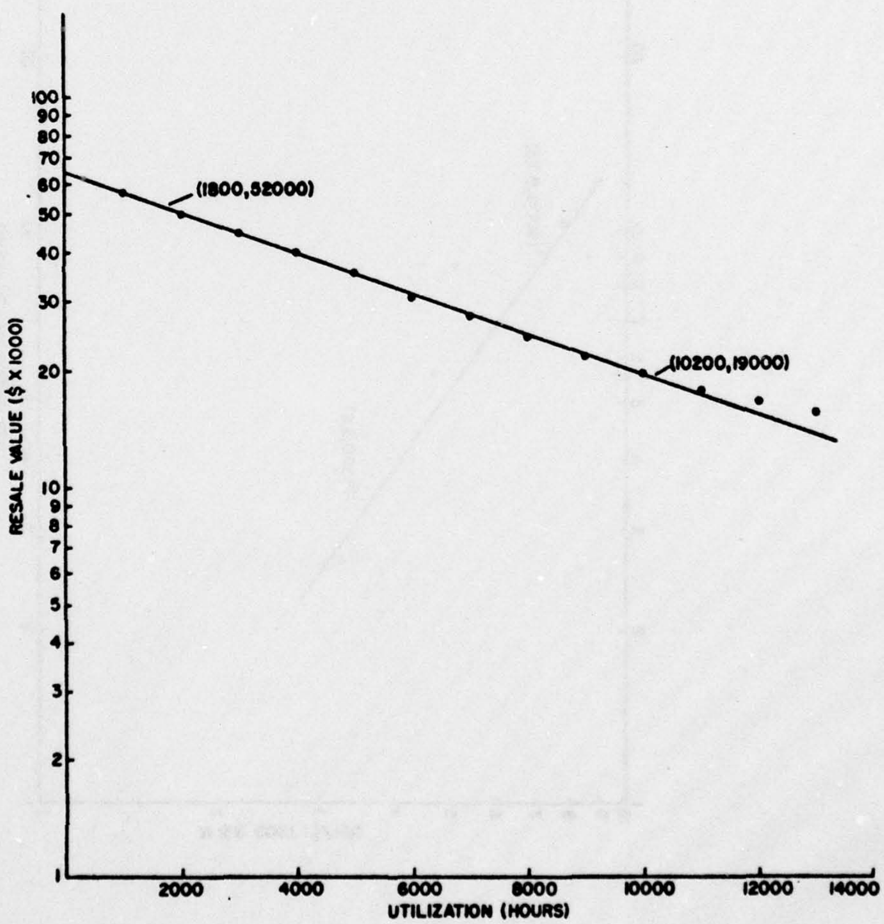

Figure D1. Plot of depreciation data.

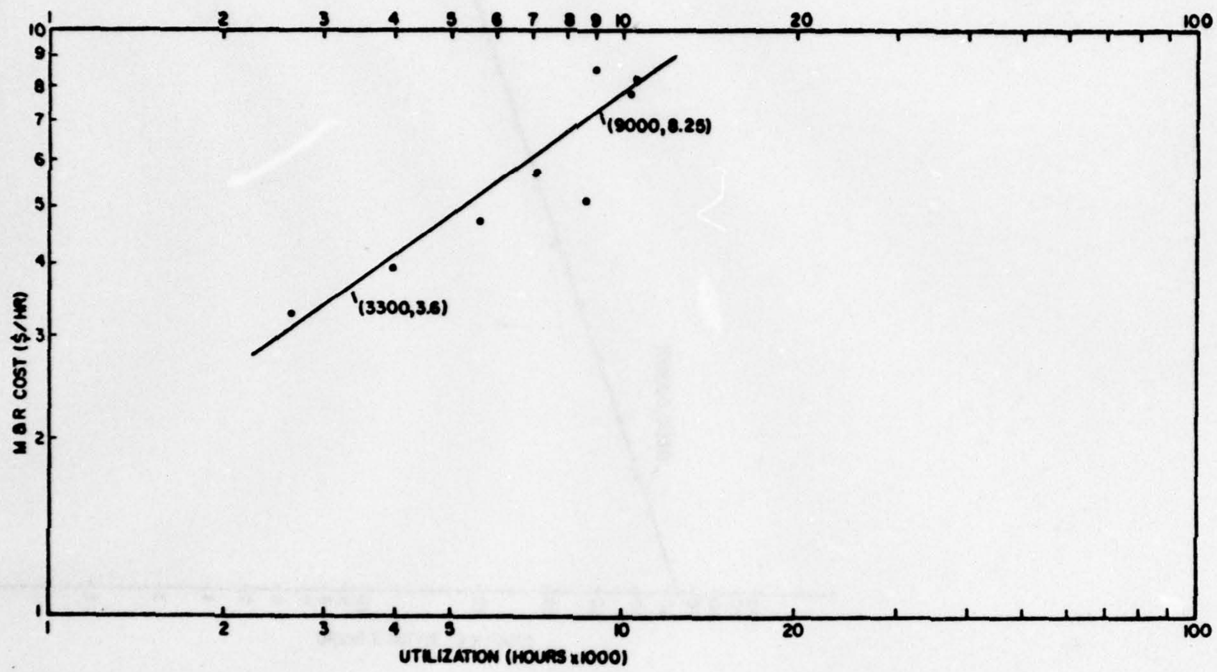

Figure D2. Plot of M&R Cost data.

APPENDIX E:

SENSITIVITY ANALYSIS

Procedure

Three categories of equipment were selected for the sensitivity analysis: heavy tractor, motorized roller, and road grader. Data were collected for each to determine input cost parameters a, F, I, K, k, and R. Using the O&O cost model, the minimum and objective utilization standards were then calculated for each equipment type. Table E1 summarizes the results for the computed cost parameters and the utilization standards.

Each of the cost parameters were then varied plus and minus 20-percent of its original value. The utilization standards were calculated for this variation in one parameter while the remaining parameters retained their original values. From experience with the model, a 20 percent deviation is believed to be a liberal estimate of the possible range of these parameters.

Results

Depreciation Coefficient a

Figures E1 and E2 illustrate the sensitivity of the utilization standards to variations in a. As shown, variations in this parameter, within the range examined, have a negligible effect on the resulting minimum and objective utilization rates.

Resale Value Ratio F

Figures E3 and E4 show the impact of variations in F on the resulting utilization standards. For the minimum utilization, the effect of variation in F is negligible for the tractor and grader and, although slightly more pronounced, considered insignificant for the roller. The objective utilization is essentially insensitive to variations in F.

Initial Investment I

The sensitivity of the standards to variations in I is shown in Figures E5 and E6. Minimum utilization for the roller exhibits significant sensitivity to I. This sensitivity can be attributed to a relatively lower initial investment in comparison to the grader and tractor. For the grader and roller, a 20 percent change in I creates just over 5 percent change in μ_{min}. In μ_{obj}, a 10 to 15 percent change is produced by the variation in I.

Table E1

Original Data for Sensitivity Analyses

TRACTOR,FT,HEAVY:INTERNATIONAL TD-25 SER. B 185 HP DSL DIR DRV 48562 LB

INITIAL PRICE, I	60831.	DOLLARS
DEPRECIATION SHAPE FACTOR,A	.0001074	
INITIAL SALVAGE VALUE:PRICE RATIO,F	.8302	
DESIGN LIFE, LD	10.0	YEARS
M&R SHAPE FACTOR, KS	1.02	
M&R SCALE FACTOR, K	.0004554	
RENTAL COST, R	21.09	DOLLARS/HR
MINIMUM UTILIZATION RATE	356	HOURS/YEAR
OBJECTIVE UTILIZATION RATE	1127	HOURS/YEAR

ROLLERS,MOTORIZED; HUBER T-58-H TANDEM GAS DRVN 11700 LB

INITIAL PRICE, I	14525.	DOLLARS
DEPRECIATION SHAPE FACTOR, A	.0001192	
INITIAL SALVAGE VALUE:PRICE RATIO,F	.9088	
DESIGN LIFE, LD	10.0	YEARS
M&R SHAPE FACTOR, KS	1.22	
M&R SCALE FACTOR, K	.0000115	
RENTAL COST, R	2.79	DOLLARS/HR
MINIMUM UTILIZATION RATE	889	HOURS/YEAR
OBJECTIVE UTILIZATION RATE	1265	HOURS/YEAR

GRADER, ROAD MOTORIZED; LETOURNEAU WESTINGHOUSE 440-H 145 HP DSL PWR 24345 LB

INITIAL PRICE, I	39657.	DOLLARS
DEPRECIATION SHAPE FACTOR,A	.0001225	
INITIAL SALVAGE VALUE:PRICE RATIO,F	.7565	
DESIGN LIFE, LD	10.0	YEARS
M&R SHAPE FACTOR, KS	.93	
M&R SCALE FACTOR, K	.0003778	
RENTAL COST, R	14.47	DOLLARS/HR
MINIMUM UTILIZATION RATE	321	HOURS/YEAR
OBJECTIVE UTILIZATION RATE	1668	HOURS/YEAR

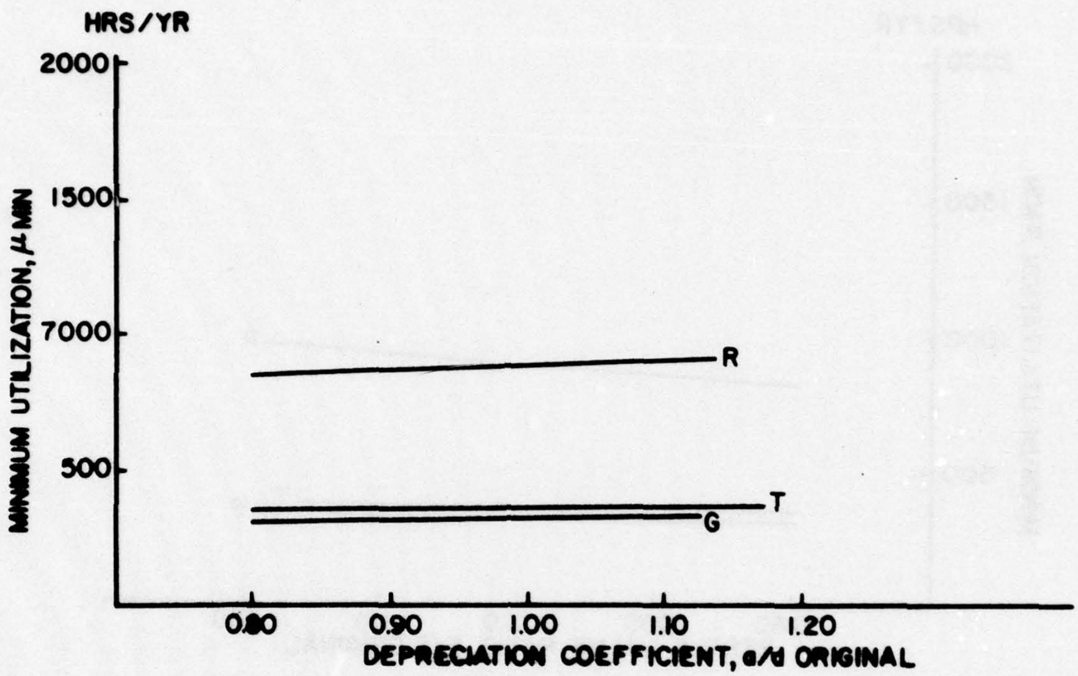

Figure E1. μ_{min} vs a.

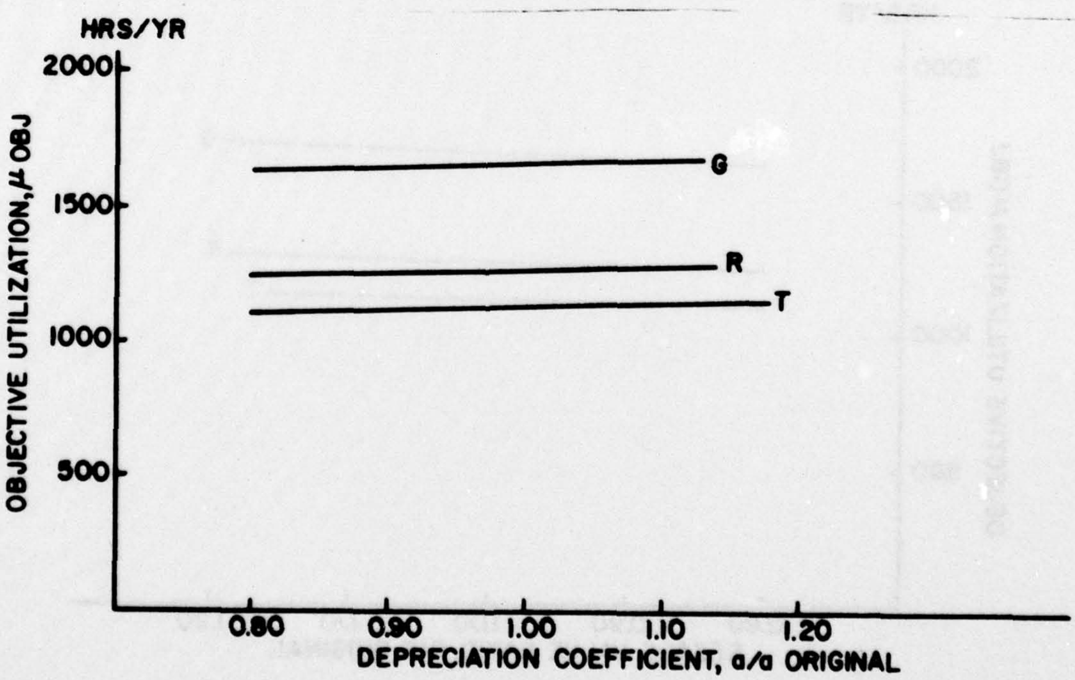

Figure E2. μ_{obj} vs a.

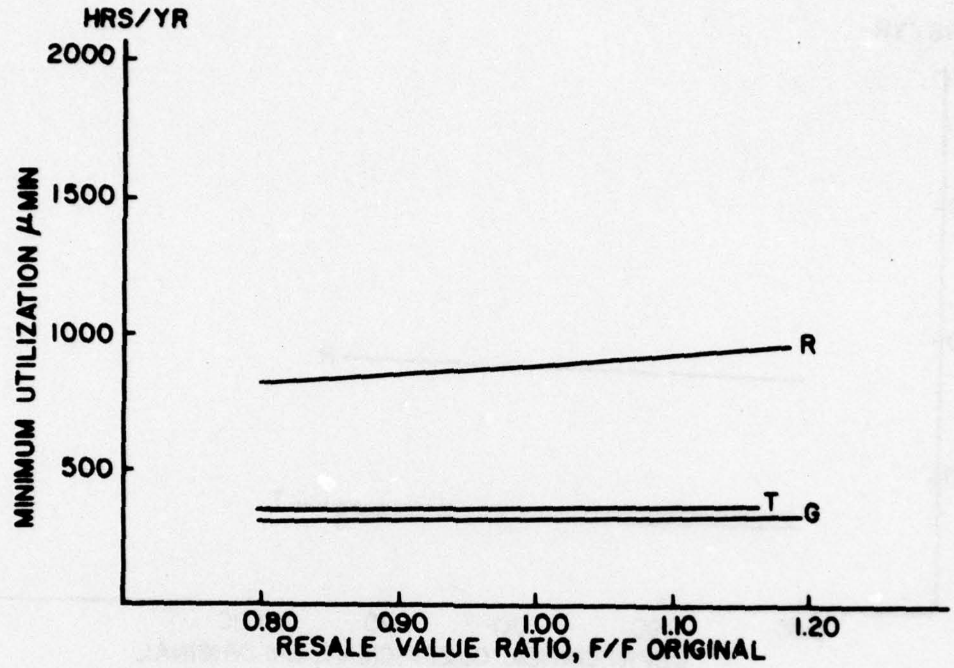

Figure E3. μ_{min} vs F.

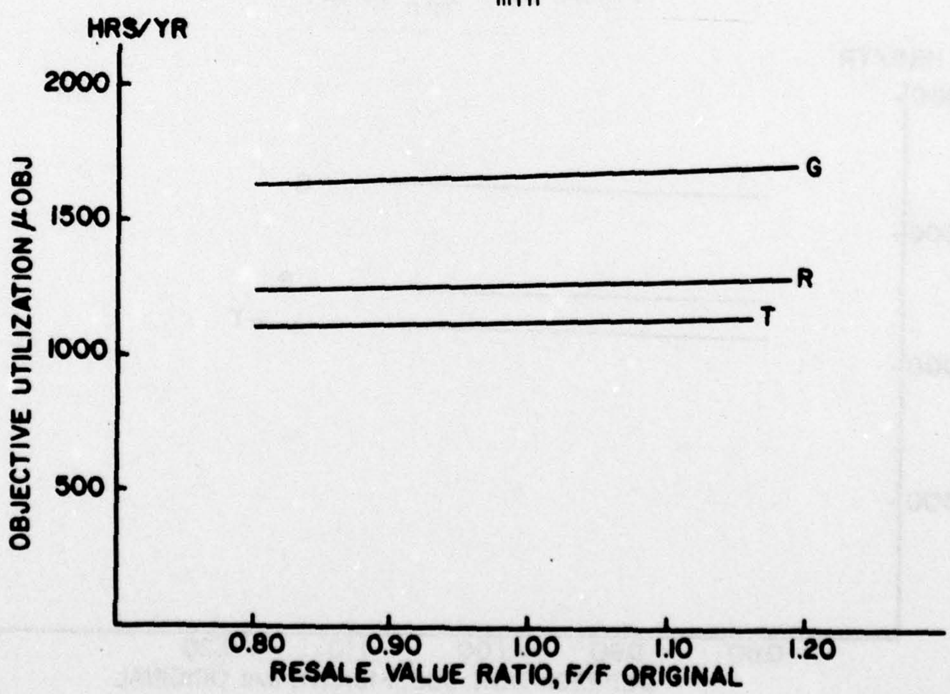

Figure E4. μ_{obj} vs F.

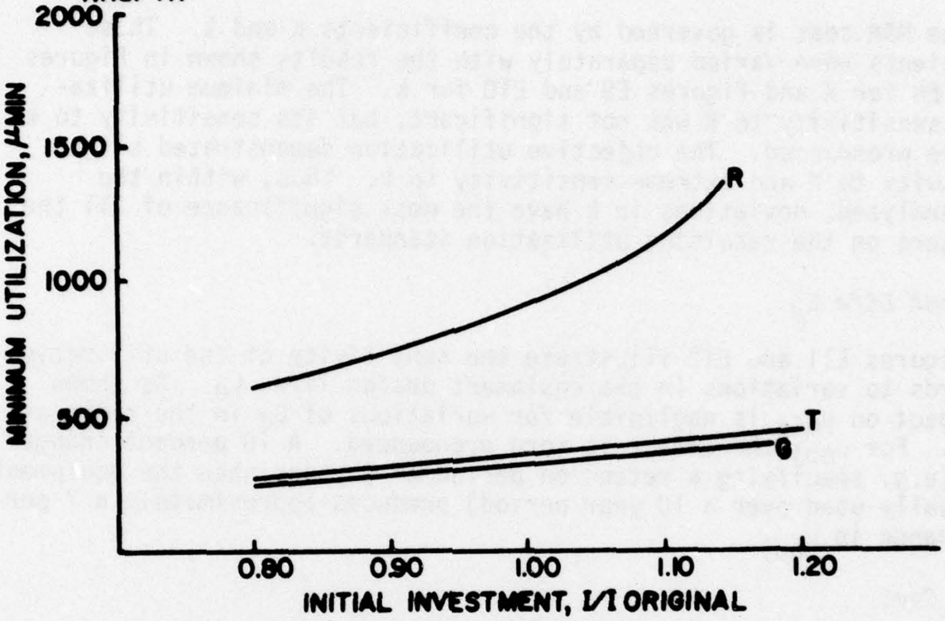

Figure E5. μ_{min} vs I.

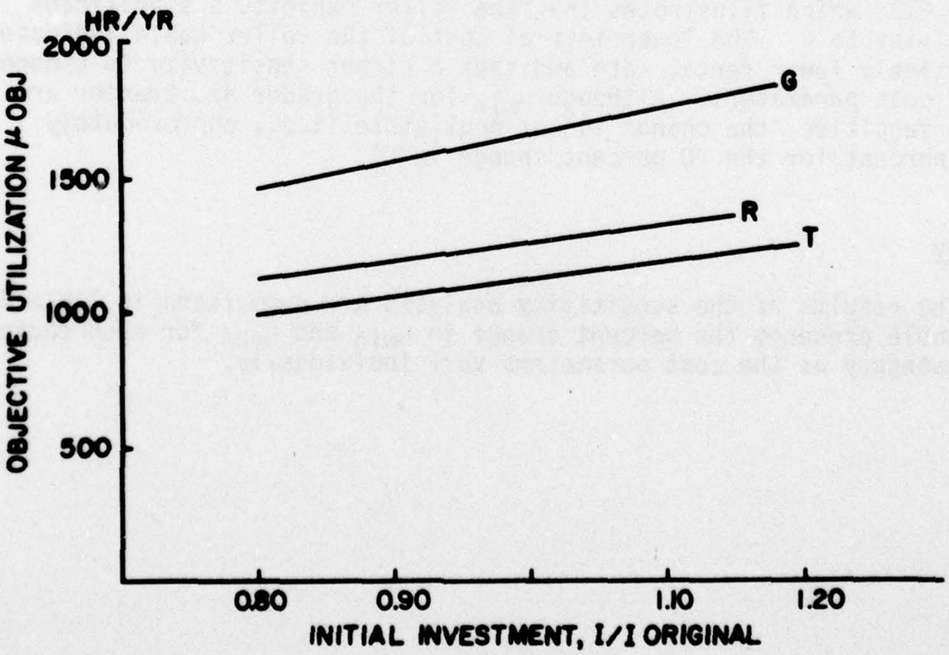

Figure E6. μ_{obj} vs I.

M&R Coefficients K and k

The M&R cost is governed by the coefficients K and k. These coefficients were varied separately with the results shown in Figures E7 and E8 for K and Figures E9 and E10 for k. The minimum utilization's sensitivity to K was not significant, but its sensitivity to k was more pronounced. The objective utilization demonstrated slight sensitivity to K and extreme sensitivity to k. Thus, within the range analyzed, deviations in k have the most significance of all the parameters on the resulting utilization standards.

Equipment Life L_d

Figures E11 and E12 illustrate the sensitivity of the utilization standards to variations in the equipment design life, L_d. As shown the impact on μ_{min} is negligible for variations of L_d in the range examined. For μ_{obj} the effect is more pronounced. A 10 percent change in L_d (e.g. specifying a retention period of 9 years when the equipment is actually used over a 10 year period) produces approximately a 7 percent change in μ_{obj}.

Rental Cost

Since the rental cost does not influence the computation of μ_{obj}, only the sensitivity of μ_{min} was examined. The results are shown in Figure E13, which illustrates that the roller exhibits a significant sensitivity to R. The lower initial cost of the roller would indicate a relatively lower rental rate and thus a higher sensitivity to changes in the cost parameters. Although μ_{min} for the grader and tractor are not as sensitive, the change is not negligible (i.e., approximately 10-15 percent for the 20 percent change in R).

Summary

The results of the sensitivity analysis are summarized in Table E2. This table presents the percent change in μ_{min} and μ_{obj} for each equipment category as the cost parameters vary individually.

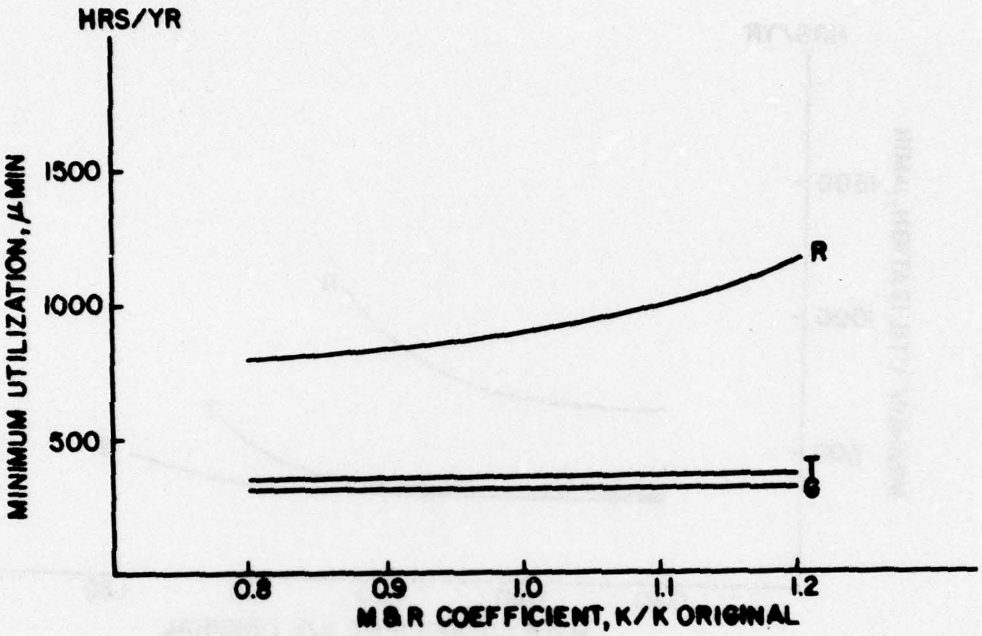

Figure E7. μ_{min} vs K.

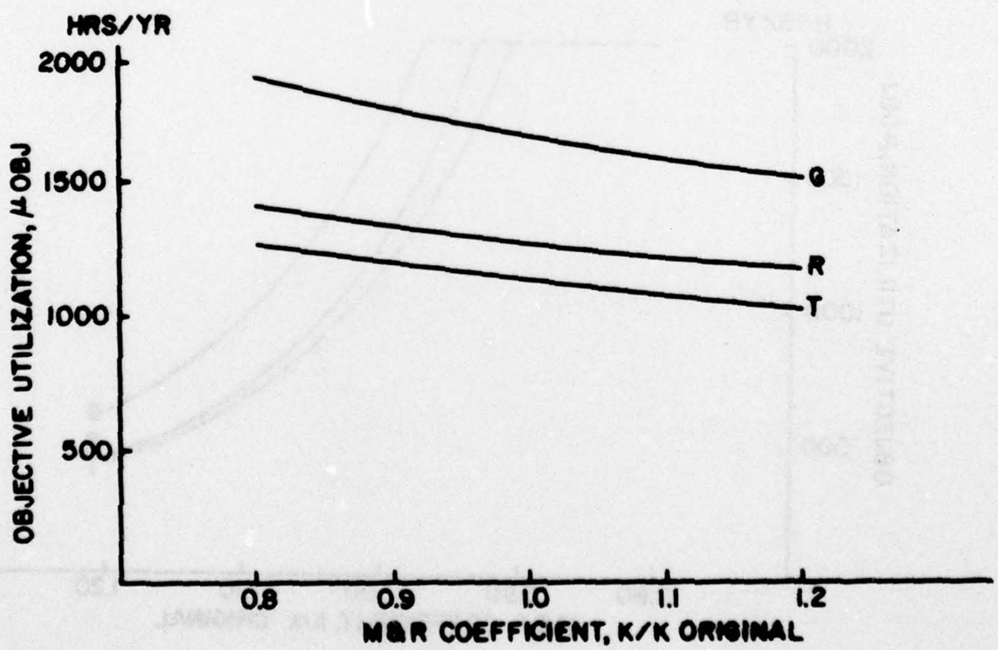

Figure E8. μ_{obj} vs K.

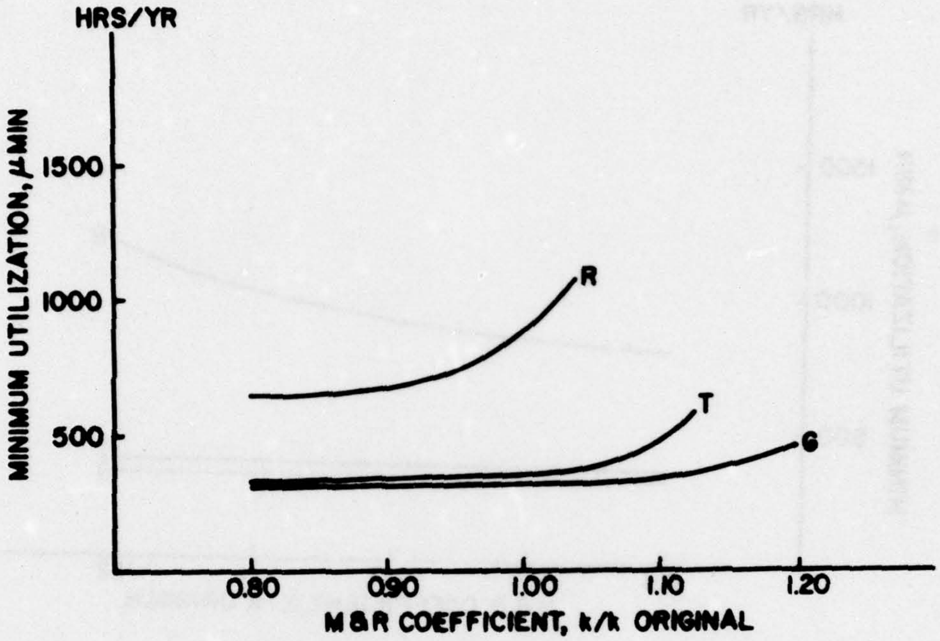

Figure E9. μ_{min} vs k.

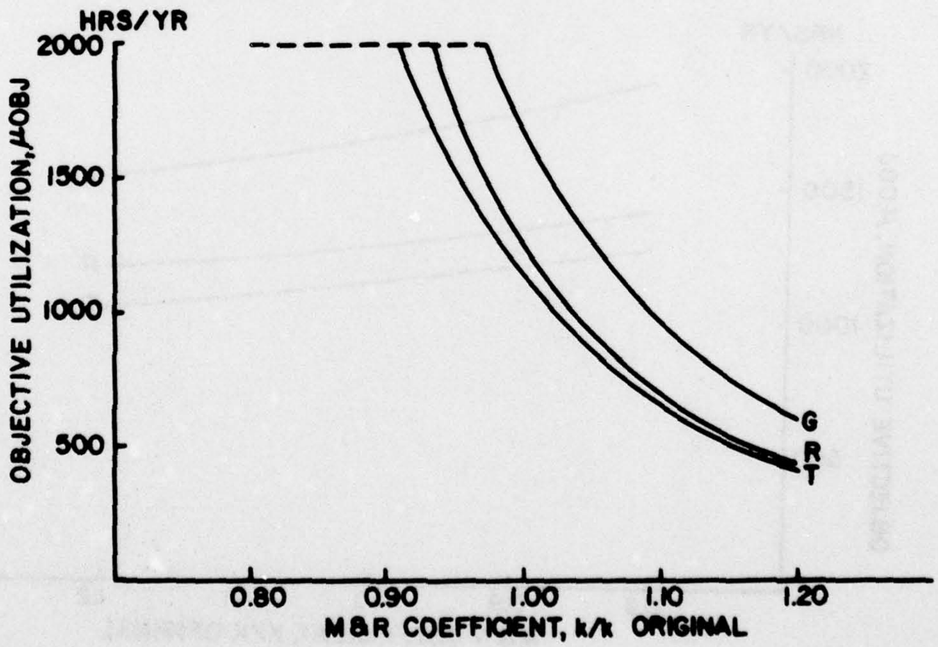

Figure E10. μ_{obj} vs k.

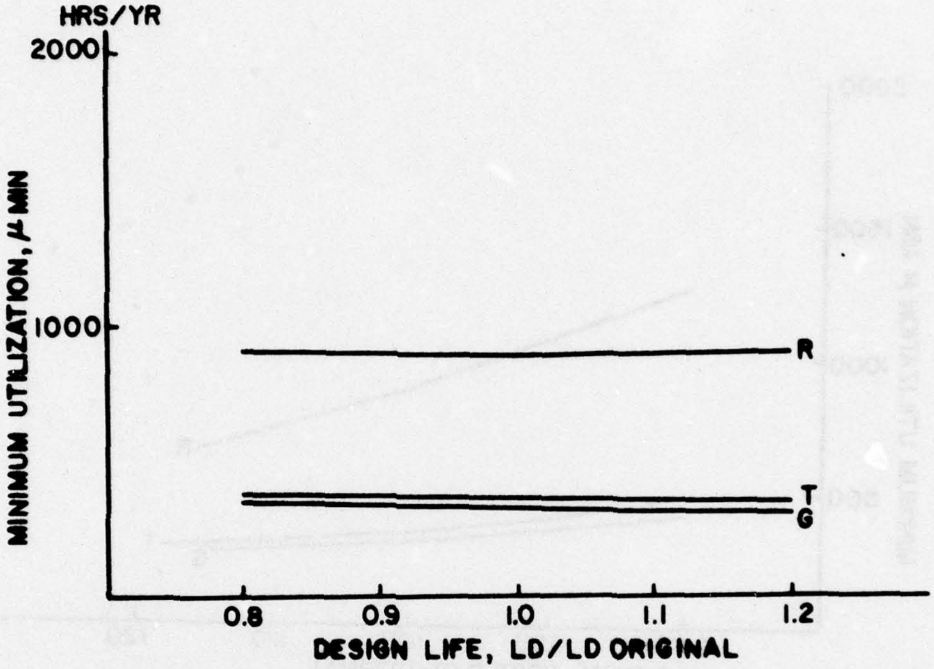

Figure E11. μ_{min} vs L_d.

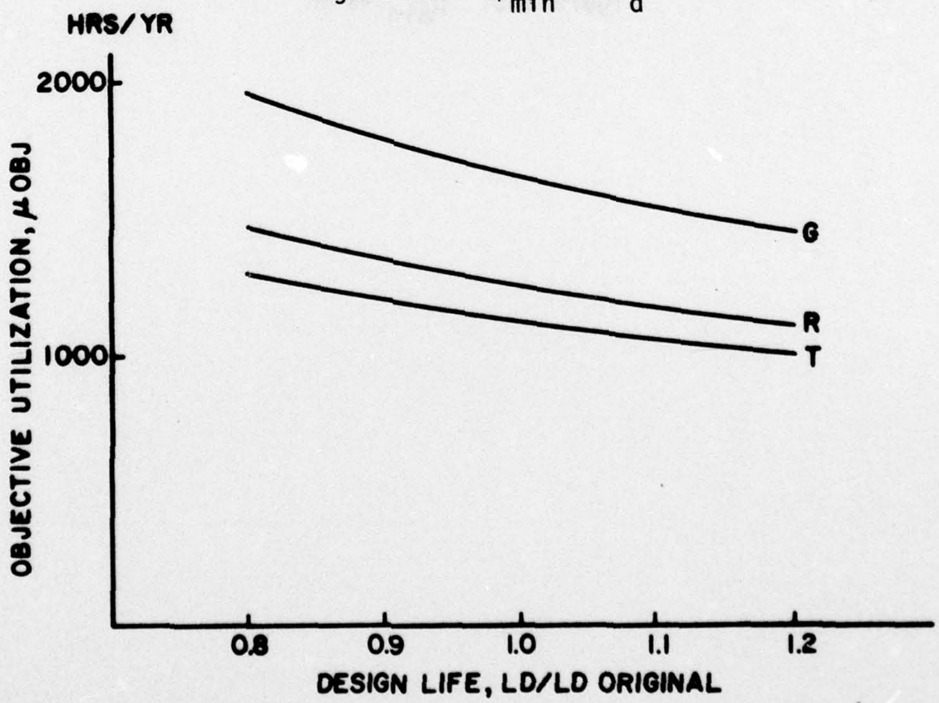

Figure E12. μ_{obj} vs L_d.

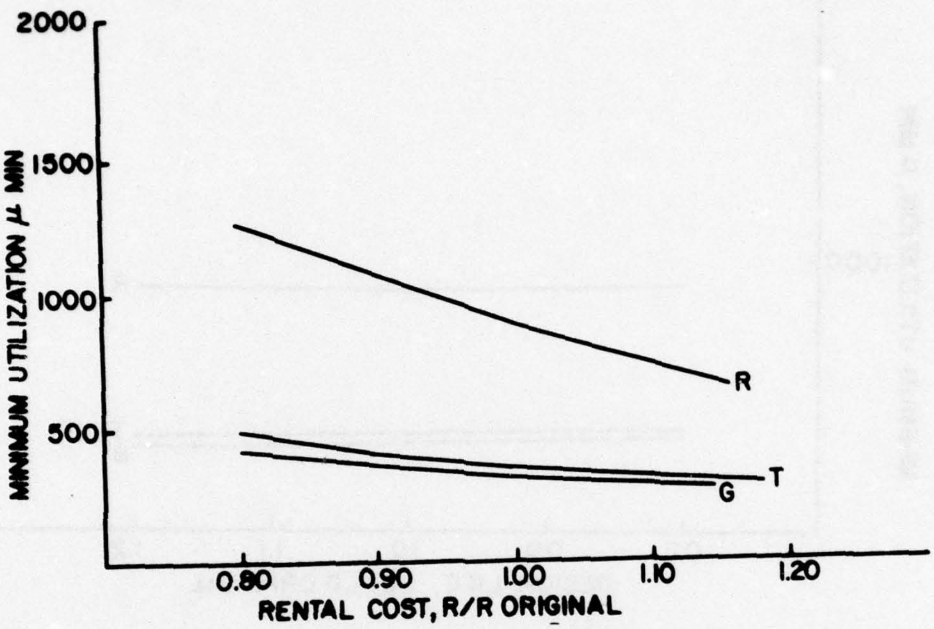

Figure E13. μ_{min} vs R.

Table E2

Sensitivity Summary

	Δ	$\% \Delta \mu_{min}$ Roller	Tractor Heavy	Grader	$\Delta \mu_{obj}$ Roller	Tractor Heavy	Grader
	-10%	-2	-1	-1	-1	-1	-1
	- 5%	-1	0	0	0	0	0
% Δ	0	(889)	(356)	(321)	(1265)	(1127)	(1668)
in a	+ 5%	+1	0	+1	0	0	0
	+10%	+2	+1	+2	+1	+1	+1
	-10	-4	-1	-1	-1	-1	-1
	- 5	-2	0	0	0	0	0
% Δ	0	(889)	(356)	(321)	(1265)	(1127)	(1668)
in F	+ 5	+2	0	0	0	0	0
	+10	+4	+1	+1	+1	+1	+1
	-10	-18	-10	-12	-5	-5	-5
	- 5	- 9	- 5	- 6	-3	-3	-3
% Δ	0	(889)	(356)	(321)	(1265)	(1127)	(1668)
in I	+ 5	+12	+ 5	+ 6	+3	+3	+3
	+10	+28	+10	+12	+5	+6	+6
	-10	-24	- 6	- 1	*	*	*
	- 5	-19	- 3	0	+37	33	*
% Δ		(889)	(356)	(321)	(1265)	(1167)	(1668)
in k	5	*	+ 8	+ 3	-26	-24	+24
	10	*	+28	+ 6	-43	-41	-41
	-10	- 6	- 1	0	+ 5	+ 6	+ 6
	- 5	- 3	0	0	+ 2	+ 3	+ 3
% Δ		(889)	(356)	(321)	(1265)	(1127)	(1668)
in K	5	+ 4	0	0	- 2	- 3	- 2
	10	+10	+ 1	0	- 4	- 6	- 5
	-10%	+ 1	+ 3	+ 4	+ 8	+ 7	+ 8
	- 5%	0	+ 1	+ 2	+ 4	+ 3	+ 4
%Δ	0	(889)	(356)	(321)	1265)	(1127)	(1668)
in L_d	+ 5%	0	- 1	- 2	- 3	- 3	- 4
	+10%	0	- 2	- 2	- 7	- 6	- 7
	-10	+20	+14	+16			
	- 5	+10	+ 7	+ 8			
% Δ		(889)	(356)	(321)			
in R	5	- 9	- 4	- 6			
	10	-18	- 8	- 9			

* Indeterminate

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1. U.S. Army-equipment. 2. Industrial equipment-management. I. Chovichien, Visuth. II. Title. III. Series: U.S. Construction Engineering Research Laboratory. Interim report ; M-247.